Copy 4

COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

RECORDS 1953, No. 59

GEOPHYSICAL SURVEY OF THE TREVALLYN TUNNEL LINE, LAUNCESTON, TASMANIA

by

J. H. QUILTY

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORDS 1953, No. 59

GEOPHYSICAL SURVEY OF THE TREVALLYN TUNNEL LINE, LAUNCESTON, TASMANIA

by

J. H. QUILTY

RECORDS 1953, No. 59

GEOPHYSICAL SURVEY OF THE TREVALLYN TUNNEL LINE, LAUNCESTON, TASMANIA

by

J. H. QUILTY

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

At the request of the Tasmanian Hydro-Electric Commission, a geophysical survey was carried out along a tunnel line at Trevallyn, a suburb of Launceston, North Eastern Tasmania.

The excavation of the Trevallyn tunnel is part of the Hydro-Electric Trevallyn Power Development project to utilise the water of the South Esk river for generation of electric power. The construction works are already well advanced. A dam is being built on the river at the Second Basin. Water from the catchment will be diverted through a tunnel two miles long to a power station, situated at sea level on the Tamar River. A locality map is given in Plate 1.

Three geophysical exploration methods, electrical, seismic and gravitational, were used to locate deeply weathered and fractured zones in the dolerite bedrock, through which the tunnel is being driven.

Two geophysicists of the Bureau of Mineral Resources, assisted by two Commission employees, completed the field measurements in ten working weeks during the summer months, November, December, 1952, and January, 1953. It is desired to acknowledge the co-operation of Dr. S. W. Carey, Geological Consultant to the Hydro-Electric Commission. The discussions between Dr. Carey and officers of the Bureau were particularly helpful in the planning of the survey and interpretation of the results.

11. PURPOSE OF GEOPHYSICAL SURVEY

The Trevallyn tunnel will consist of two parts, one 7,200 feet long from the Second Basin to the Glen Dhu fault and the other, 3,000 feet long, which continues from Pitt Avenue, down to the power station at the West Tamar Road. (Locality map, Plate 1.).

At the time the geophysical survey was requested, the latter part had been excavated. From the Glen Dhu fault towards the Second Basin the tunnel had been driven for about 2,500 feet, but difficulties were being encountered owing to the fact that the zones of fractured and weathered rock at the tunnel level were considerably more numerous than had been expected. This resulted in a slowing down of the work and also created the problem of providing additional materials for supports and lining in excess of the originally estimated requirements.

The aim of the geophysical survey was to determine the location and extent of zones of fractured and weathered rock in the remaining 5,000 feet of the tunnel line between the Second Basin and the Glen Dhu fault. If such information could be provided in advance, it would be valuable in predicting where bad rock would be encountered and would enable a better estimate to be made of what proportion of the remainder of the tunnel would be likely to require lining and supports.

111. GEOLOGY OF THE AREA

For a full description of the geological history of the Launceston area, the reader is referred to "Geological Report of the Launceston Quadrangle S.E. Quarter" by S. W. Carey D.Sc. (1947).

The following is a summary of the geological events and processes which concern the area under investigation.

The course of the tunnel lies through dolerite, a medium to coarse-grained basic igneous rock intruded as sills of great thickness into Permian sediments during the Jurassic period, and now exposed in many parts of the state of Tasmania. The roof rocks of the dolerite sills and much of the dolerite itself were stripped off in a long period of weathering and denudation which followed the intrusion. The resultant Lower Tertiary peneplain of dolerite, capped with bauxite and laterite in many places, was broken up during the early Miocene by violent faulting. In the Launceston area, a series of major step faults with a general north-west trend, formed steep fault scarps, which are the present main topographic features. The Trevallyn Fault scarp is a natural boundary between Trevallyn suburb (average elevation 400 feet) and the Launceston city area (sea level). The scarp of the Glen Dhu fault, which the tunnel line crosses at right angles, is approximately 300 feet high.

In addition to these primary faults, there are two pronounced systems of joints in the dolerite, prominently exposed in the South Esk gorge, and in the quarry at Trevallyn bridge. In one system, the joints trend in a north-west direction parallel to the major faults, and probably range in magnitude from mere joints with little or no differential movement through small faults with a few feet of movement up to the size of fairly important faults. Almost at right angles to this system is another system of joints trending north-east. The joint systems have been the controlling factor in the development of the stream pattern in the district. Many of the major joints, traced from aerial photographs are shown on a map accompanying the abovementioned report. Two of them cross the tunnel line as shown in Plate 1. However, the report states, the selection of those to be included in the map is rather arbitrary since the shears and joints range in size from major fractures to closely spaced joints at intervals of 2 or 3 feet.

Fracturing and subsequent weathering along these faults and joint planes have extended to depths of at least 300 feet below the surface in places along the tunnel line, as revealed by the excavations to date. In the section shown in Plate 2, the shaded portions of the tunnel show where unsound rock has been encountered and steel supports have been required. In these places, the dolerite in general is shattered into fragments and strongly weathered and in two such places strong flows of water were met. In the unshaded portion of the tunnel section, where the rock is sound in the sense that supports were not required, the dolerite shows irregular jointing, with calcite veins filling some of the joints. Polished facetted surfaces (slickensides), formed by the differential movement of fault blocks, were visible at one of the abrupt contacts between sound and unsound rock.

The logs of eight bore holes, drilled at the positions indicated on the tunnel line section (plate 2.), show that the depth of overburden, consisting of soils, clays and weathered dolerite, varies greatly. The grain size of the fresh dolerite in the drill cores varies from medium to coarse; chloritized joints and calcite veins are common. In some of the holes, sound dolerite is continuous for several hundred feet to tunnel level, but in others, alternate solid and soft patches have been penetrated by the drill.

IV. RESISTIVITY SURVEY.

Principle of the Method.

A wide range of electrical resistivities is exhibited by the rocks of the earth's crust. The flow of electric current through non-metallic rocks is almost entirely ionic conduction in the solutions contained in the rock pores. The conductivity (and hence its reciprocal, the resistivity), is dependent therefore on the porosity, degree of saturation of the rock and the salinity of the solutions. High resistivities are usually associated with dry loose surface soils, sand, gravel and crystalline rocks; much lower resistivities are encountered in clays and silts.

In the present survey, the method used in measuring resistivities is in principle the standard Gish-Wenner-Rooney method. Four electrodes are placed in the ground at equal intervals along a straight line. A current I is introduced into the ground through the two outer electrodes and the resulting potential difference E between the two inner electrodes is measured. In the ideal case of a homogeneous isotropic earth, it may be shown that the earth resistivity R is given by the expression, $R = 2\pi a \frac{E}{I}$, where 'a' is the electrode separation, i.e. the distance between two adjacent electrodes or one third of the separation between the other (current) electrodes. In practice, layers of different resistivities are usually present below the surface, and the quantity $2\pi a \frac{E}{I}$ derived from the observations is termed the apparent resistivity (Ra).

The effective depth of the current flow and hence of the resistivity measurement is increased by increasing 'a'. Hence, if the earth consists of horizontal layers of different resistivities, the presence of successively deeper layers is reflected by the manner in which Ra changes with increasing 'a'. In general it may be assumed that Ra is the average resistivity of the rocks between the surface and a depth approximately equal to 'a'. The relationship is approximate only, as the effective depth of measurement can be influenced by the relative resistivities of the different layers, owing to the tendency for the current flow to be concentrated in layers of lowest resistivity.

Equipment and Field Procedure.

The current electrodes used were stout metal spikes driven into the ground. The potential electrodes were porous pots, filled with a saturated solution of copper sulphate, in which copper electrodes were immersed. The use of such electrodes eliminates contact potentials at the surface. Radio "B" batteries supplied the current to the outer electrodes. A new resistivity meter, designed and built in the Bureau, enabled the voltage-current ratio to be measured directly.

The unit of resistivity used in the ohm-centimetre, being the value in ohms per cubic centimetre of the rock.

In the Trevallyn survey, two different applications of the method were used, viz., the "expanding electrode" and "constant separation" techniques.

Expanding Electrode Method.

The apparent resistivity is observed for values of 'a' from 1½ feet to a maximum of several hundred feet or more depending on the depth to be investigated. A maximum electrode separation of 500 feet was used in the Trevallyn tests. As 'a' is increased, the electrodes remain symmetrically placed about the central point of the spread. When Ra is plotted against 'a', a curve (referred to in this report as a depth profile) is obtained, the form of which will depend on the resistivities and thicknesses of the underlying layers.

Several different methods have been employed for the determination of the depths to the horizontal interfaces from the depth profile. The method which has been found most satisfactory is based on the fitting of standard theoretical curves to the observed profiles. Standard two-layer curves have been computed, giving the variation of Ra with 'a' for one uniform horizontal layer overlying another of infinite thickness. The complete range of possible ratios of the upper resistivity r_1 to the lower, r_2, is covered. The parameter used in the family of curves is $\frac{r_2 - r_1}{r_2 + r_1}$ which ranges between limits of +1 and -1. In the standard and observed curves, logarithmic plotting is used. This makes the shape of the curves independent of the units used, and facilitates the comparison between observed and standard curves. If a satisfactory fit is obtained, the depth of the interface can be simply read off on the electrode separation scale.

The usefulness of the two-layer curves has been extended by a principle known as Hummel's substitution principle, by which a two-layer combination may be replaced by a single layer for electrode separations large in comparison with the combined thickness. By using this principle, a depth profile representing several layers may be treated by successive applications of the two-layer curve-fitting process. The method of interpretation outlined above necessarily assumes that the layers are uniform, horizontal and of infinite extent. Clearly, lateral variations of resistivity, or progressive gradual changes of resistivity with depth tend to reduce the reliability of the interpretation.

Constant Electrode Separation Method.

In this application, sometimes called "resistivity mapping" the electrode separation is kept constant and the electrode arrangement as a whole is moved along the traverse line. The observations show lateral variations of apparent resistivity between the surface and a more or less constant depth approximately equal to the particular electrode separation used. By showing the lateral variations of resistivity, the method has proved to be of considerable use in the investigation of fault zones, contacts of different formations and lenticular beds of materials such as gravel and sand occurring in clays or silts.

A disadvantage shared by both the expanding electrode and constant electrode separation methods is that the observed apparent resistivity values are strongly affected by surface conditions. Large variations in the resistivity of the surface soil will tend to mask the effects of deeper changes in resistivity and may limit the application of resistivity methods in some areas.

Application of Resistivity Method in Trevallyn Tunnel Investigations.

The tunnelling so far carried out has shown that unsound sections of rock include a large proportion of weathered dolerite and clay. It would be expected that the high porosity of these materials would cause any unsound section of dolerite to have a much lower resistivity than that of solid dolerite. The resistivity survey was planned on the assumption that this difference in resistivity would enable zones of fractured or extensively weathered dolerite to be differentiated from the solid dolerite.

The characteristic resistivities of the solid dolerite, weathered dolerite and surface soil in the area were determined from expanding electrode tests at three points along the tunnel line and from detailed tests alongside a nearby road cutting. The observational data from these tests are shown in Plate 2, Figs. 2 and 3. In the plotting of the depth profiles the small circles indicate the points obtained by plotting the apparent resistivity against the electrode separation, and the heavy curves are the theoretical two-layer curves which give the best fit with the observed profiles. K is the value of the parameter $\frac{r_2 - r_1}{r_2 + r_1}$ for the particular two-layer curve selected.

The expanding electrode tests on the tunnel line will be referred to again in a subsequent section, but it is appropriate here to discuss the findings as to typical resistivity values. In these tests, the line of the electrode spread was parallel to the tunnel line. The depth profiles for the tests at pegs 8.5, 23.5 and 60 on the tunnel line show three main layers. The top layer is surface soil down to a depth of about one foot with resistivity between 3,000 to 30,000 ohm-cm. Below this there exists a layer of lower resistivity between 700 and 2,700 ohm-cm, which is assumed to consist of alluvium, clay and weathered dolerite, in a saturated state. In two of the tests the interpretation suggests that this layer may actually consist of two separate layers but it is not possible to identify the layers with certainty. The third layer is solid dolerite which gives the profile the trend towards high resistivity values for the larger separations. If the dolerite were homogeneous and its upper surface a horizontal plane, the profile would approach asymptotically the resistivity value of solid dolerite. But the observed values at the largest separations show departures from the theoretical curve, which are probably due to lateral variations of resistivity caused by the irregular weathering of the dolerite. It is considered that the result will be to make the resistivity values for dolerite, namely 45,000, 55,000 and 60,000 ohm-cm., as deduced from the interpretation with standard curves, somewhat too low. Furthermore, the results (discussed in detail later) from the constant separation observations near the south-western end of the tunnel line where solid dolerite is known to be very close to the surface, suggest the the resistivity of fresh dolerite is of the order of 70,000 ohm-cm. It is considered that the true resistivity of fresh dolerite is probably between 60,000 and 80,000 ohm-cm.

The results of tests near the road cutting are given in 3A and 3B of Plate 2. The section exposed by the 20 feet cutting consisted of rounded dolerite boulders two to three feet in diameter with weathered skins but fresh cores in a matrix of moist reddish-brown sandy clay. Nine inches of hard bleached topsoil covered the clay.

The depth profile 3A, taken to maximum 'a' of 64 feet, shows three layers. The first, with resistivity 3,000 ohm-cm and one foot in thickness, corresponds to the topsoil. The material within the second layer, resistivity 400 ohm-cm., was predominantly clay with a few small dolerite boulders. In the third layer, resistivity 2,000 ohm-cm., the dolerite boulders were larger and more numerous.

Two short traverses, one with electrode separation of 5 feet and the other 10 feet, were made over the same area. The two profiles are shown in Fig. 3B. For a separation of 5 feet, the resistivities range from 600 to 1,500 ohm-cm.; for 10 feet separation, they range from 400 to 2,000 ohm-cm. As in 3A, the greatest resistivity values are obtained at the deeper penetration.

The results of the tests 3A and 3B indicate that the resistivities of the weathered materials range from 400 to 2,000 ohm-cm. at moderate depths, and are dependent on the extent of decomposition of the dolerite.

Summarising the foregoing discussion, it may be stated that the resistivity of fresh dolerite is about 70,000 ohm-cm., and that of the weathered materials (excluding surface topsoil) about 2,000 ohm-cm. or less.

It should be noted, however, that as the weathering of dolerite commonly takes place along fault and joint planes, the average resistivity of a volume of partially weathered dolerite may range within wide limits, depending on the extent to which the weathering has progressed, so that a section of rock actually unsound for tunnelling may have a resistivity considerably higher than the value adopted for the weathered materials.

The resistivity survey of the Trevallyn tunnel line consisted mainly of constant separation observations, as it was considered that the recording of lateral changes of apparent resistivity along the tunnel line would be of most value. Only a limited number of expanding electrode tests were made, and these were mainly for the purpose of finding out the typical variations of resistivity with depth through the section from the surface to the solid dolerite. As will be outlined in the report, ambiguities which are common in resistivity interpretation were reduced by the use of two other independent geophysical methods, viz., seismic and gravity methods.

Constant Electrode Separation Results.

Measurements of apparent resistivity were made at intervals of 50 feet along the tunnel line. Electrode separations of 50 feet, 100 feet and 200 feet were used, giving thereby profiles for three different effective depths of measurement. The profiles are shown in Plate No. 2, Fig. 1.

As the high resistivity dolerite is overlain by an overburden of much lower resistivity, the profiles will show high values where the overburden is thin and vice versa, provided the depth to the dolerite remains within the depth range of resistivity measurement for the particular electrode separation used. Hence the profiles may be interpreted in terms of the relative thickness of the overburden material. Particular attention must be given to steep gradients in the profile, because they may be due to abrupt lateral changes of resistivity associated with deeply weathered zones or faults crossing the tunnel line. It is obvious that the method will be limited in its ability to detect very narrow zones of low resistivity within the dolerite as the voltage- current ratios necessarily indicate average values over the distance between the potential electrodes.

The resistivity profiles from the beginning of the traverse at peg 0 to peg 23 can be compared with the known rock conditions in the part of tunnel already excavated.

Between peg 14 and peg 16, the drop on all three profiles indicates a deeply weathered zone extending to a depth greater than 200 feet. The effect of the higher resistivity dolerite on either side will tend to make the value of the resistivity minimum somewhat higher than the true value at the centre of the zone, particularly for 'a' = 200 feet. In the tunnel, unsound rock was encountered in a position which coincides exactly with the resistivity indication.

The comparatively high values of resistivity between pegs 10 and 14 and between pegs 17 and 20 are attributable to a decrease in thickness of the overburden on either side of the deeply weathered zone referred to above.

Particular attention is drawn to the gradient in the profile between pegs 8 to 10, and to the steeper gradient in the vicinity of peg 20.5. In both places the gradients correspond to narrow zones of unsound rock in the tunnel. These shattered zones are believed to be the fracture zones between adjacent fault blocks, the change in thickness of the overburden from one block to another being reflected as a gradient in the resistivity profile. It has been mentioned that minor faults probably exist parallel to the main fault system, and in support of this there is evidence of differential movement observed in the tunnel at one of the abrupt contacts between sound and unsound rock.

From this examination of the resistivity results over the known section of the tunnel, it is considered that:-

1. Major zones of deep weathering are indicated by well-marked minima, and

2. Steep gradients are probably indications of faults, and therefore may serve to locate fracture zones extending down to tunnel level.

The results on the remainder of the tunnel line will now be discussed.

From 28 to 30, the drop in the resistivity values, most marked on the 'a' = 200 feet profile, suggests the presence of a fault. The vertical drill hole No. 2044 provides no definite evidence of a fault. However it shows that there are fairly thick weathered sections of rock at intervals down to 365 feet. The penetration of weathering processes down to this depth would have been assisted by any fracturing associated with a fault.

The low values of resistivity between 32 and 34 indicate a zone of deep weathering which, from comparison with the values over the known section 14 to 16, is considered likely to extend to tunnel level and produce poor rock conditions for a length of at least 200 feet.

Between 35 and 46, the solid dolerite is probably not deeper than 100 feet from the surface. Between 39.5 and 41.5 there is apparently a higher block of dolerite on either side of which there is the possibility of narrow fault zones.

Between 48 and 51.5, the low values on the profiles indicate another deeply weathered zone, which must extend down to tunnel level. It is considered that the tunnel will be in poor rock here over a length of at least 350 feet. This is the most important feature revealed by the resistivity survey and is confirmed by both gravity and seismic results.

Between 54 and 66, very high values of resistivity were observed and can be attributed to the closeness of the dolerite to the surface, as is also shown by the seismic work and the drill holes No. 2036 and 2037. The apparent resistivity approaches the true resistivity of the solid dolerite. The two steep troughs centred at 57 and 61, shown very strongly on the 'a' = 200 feet profile, are indicative of narrow zones of low resistivity, and could indicate fractured zones with weathering extending down to tunnel level.

Expanding electrode Tests.

The interpretation of the depth profiles shown in Fig. 2, Plate 2 gives the resistivities of the different layers, which have been referred to in some detail earlier in the report, and the depths to the interfaces.

Some additional remarks regarding the depths to solid dolerite are required.

Test No. 1 (Position, peg 60). The top of the solid dolerite at a depth of 7 feet is in good agreement with the log of the drill hole No. 2037, which shows a depth of 8 feet, and in fairly good agreement with the calculated seismic depth of 12 feet.

Test No. 2. (Position, peg 23.5). In order to achieve a reasonable fit with the standard curves, it has been necessary to assume that the section between the surface soil and the dolerite comprises two separate layers. The estimated depth to dolerite is 32 feet. No bore data is available, but the calculated seismic depth is 50 feet.

Test No. 3 (Position, peg 8.5). The observed depth profile shows the presence of four separate layers, but the irregularities in the profile, due probably to lateral variations in resistivity within the electrode spread, make it impossible to achieve very satisfactory fits with the two-layer curves. The estimated depth to solid dolerite (37 feet) is therefore not regarded as a reliable determination. It is considerably less than the calculated seismic depth (77 feet).

The main purpose served by the expanding electrode tests has been to show the variation of resistivity with the depth from the surface down to the solid dolerite and to enable quantitative estimates to be made of the typical resistivities of weathered and solid dolerite.

The difficulty in obtaining reliable interface depths from the depth profiles, as experienced in the interpretation of tests

2 and 3, is one which is frequently encountered in the use of expanding electrode method and is the main reason why the refraction seismic method is generally preferred when depths to bedrock are required.

V. SEISMIC SURVEY.

Principle of the Method.

The seismic method of exploration is based on the fact that the velocity of wave propagation differs greatly in different kinds of rocks. In seismic exploration, the only velocities taken into account are those of the fastest waves, namely the longitudinal or compression waves. Crystalline rocks have velocities in the range of 10,000 to 20,000 f.p.s., compacted sedimentary rocks 6,000 to 15,000 f.p.s., unconsolidated sediments 1,500 to 6,000 f.p.s., and surface soils 800 to 2,000 f.p.s. Wave velocity through a rock is dependent on its elastic properities, which are affected by many factors, such as texture, compaction, moisture, void space and cementation.

Seismic waves are reflected and refracted at an interface between two types of rock having different velocities of propagation, in a manner analagous to that of light waves at the boundaries of optical media. The chief objective in seismic work is to determine the distance between the earth's surface and refracting and reflecting horizons below. The interpretation is based on accurately measured travel times of the seismic waves.

In applying the seismic method to shallow depth determinations the refraction technique is used. The seismic waves are produced by small explosive charge at a depth of a few feet below the ground surface. Geophones, (detectors, sensitive to earth vibrations) set on the ground at measured distances along a straight line from the shot point are electrically connected through amplifiers to photographically recording galvanometers. The shot instant and the arrival of the first wave disturbance at each geophone are recorded and an accurate measurement is thereby obtained of the travel time of the seismic waves between the shot point and each of the geophones.

The interpretation of the observed travel time data may be explained by considering a number of horizontal layers, where each successively deeper layer has a higher velocity than the layer above it. The first waves to reach the geophones near the shot point will be those which travel directly through the first layer of low velocity. At a certain distance from the shot point, the first arrivals at the geophones will be those waves which travel down through the first layer, undergo refraction at the interface of the first and second layer and travel along this interface with the velocity of the second layer, and finally return to the surface. Geophones still further away will receive their first arrivals from waves refracted at deeper interfaces with higher velocities and so on.

The travel times of the waves are plotted against distance of the geophones from the shot point, to give a time-distance graph such as those shown in Plate No. 2, Fig. 1. From the time-distance graph, it is possible, in general, to obtain the velocities of the layers and to calculate the depths to the interfaces. From accumulated seismic data, it is known what type of material is likely to correspond to a particular velocity. For example, the solid dolerite of Tasmania exhibits a velocity of approximately 16,000 f.p.s., overburden clays and weathered dolerite 4,000 to 5,000 f.p.s., and surface soils approximately 1,000 f.p.s.

Equipment and Field Procedure.

A set of Swedish A.B.E.M. 6-channel portable recording equipment and detectors were used in the survey of the Trevallyn tunnel line. Measurements along the line were made in a series of traverses, each about 1,000 feet in length. Shot points were located at both ends of the ~~traverses~~ set up geophones, and travel times were recorded for waves travelling in both directions. This technique, known as the method of reciprocal times, is designed to give the depths to refracting surfaces below each geophone point.

Results.

Plate No. 2. Fig. 1, shows the travel times plotted against distances from the shot point for each of the traverses along the tunnel line. Three layers are evident in most of the traverses. The first layer, velocity, 1,500 f.p.s., corresponds to the surface weathered layer. The second layer, velocity 4,000 to 5,000 f.p.s., is that of the unconsolidated overburden material, consisting of clays and weathered dolerite. Refractions from the surface of the solid dolerite are indicated by those portions of the time-distance curve, in which the reciprocal of the slope is approximately 16,000 f.p.s.

The depths to the surface of the solid dolerite were calculated, and the resulting seismic bedrock profile is shown. The accuracy of the calculated depths over the tunnel line will undoubtedly be reduced by the absence of a sharp boundary between weathered rock and solid rock. In the following table, seismic results are compared with bore hole data.

COMPARISON OF SEISMIC RESULTS AND BORE HOLE DATA

Bore Hole No.	Solid Dolerite Logged in Bores	Calculated Seismic Depth to Solid Dolerite
2036	8' - 286'	5'
2037	8 - 350	12
2038 (inclined)	151 - 277 335 - 338	> 150 (no refraction from dolerite)
2039 (inclined)	73 - 75 124 - 160 170 - 201 208 - 350	70
2042	35 - 285	75
2043	12 - 216 219 - 398	10
2044	20 - 33 54 - 74 91 -121 147 - 177 193 - 232 240 - 316 324 - 347 365 - 375	53
2045	25 - 30 40 - 363 367 - 369 383 - 390	69

There is substantial agreement between the two sets of data at bore holes Nos. 2036, 2037, 2038 and 2043.

In bore holes Nos. 2039 and 2044, the alternate sections of solid and weathered dolerite in the drill core indicate the irregular weathering of the bedrock at these points. It is difficult to decide from these bore logs what figure should be taken for the depths to solid dolerite for comparison with the seismic results. The seismic depth is probably a better indication of the average depth in the immediate vicinity than is given by the bore log.

Bore Hole No. 2042, showed solid dolerite from 35 feet to 285 feet and gave no indication of the zone of unsound rock encountered in the tunnel below it. The calculated seismic depth at peg 10 close to the hole is 75 feet.

The locations of the narrow zones of weathered material encountered in the tunnel were not detectable in the analysis of the seismic record.

Between pegs 14 and 16, the velocity of waves in either direction is approximately 9,000 f.p.s., much less than the wave velocity in solid dolerite (16,000 f.p.s.). The bedrock surface is at such a depth, that the first wave disturbance to reach the geophones are those refracted from a shallower layer with lower velocity, believed to be partially decomposed dolerite. Because no refractions were recorded from the solid dolerite, no depth calculation could be made and the solid dolerite must be at least 150 to 200 feet deep in this part of the tunnel lone. It will be noted that unsound rock was encountered here at tunnel level, and that a pronounced resistivity 'low' was observed on the three constant separation profiles.

Similar velocities were recorded between pegs 48.5 and 51, and it is estimated that the depth to bedrock must be at least 150 to 200 feet. Gravitational and electrical resistivity measurements have confirmed the existence of a deep trough of weathered material in this part of the tunnel line.

The depression in the calculated seismic bedrock profile between pegs 33 and 34.5 coincides with minima on the resistivity profiles and a small negative anomaly on the gravity profile and is considered to be due to a narrow zone of deep weathering which probably goes down to tunnel level. Another narrow weathered zone probably accounts for the small depression between pegs 57 and 58. The resistivity profiles give strong confirmation of this and a slight negative anomaly is detectable on the gravity profile. It is possible therefore that between pegs 57 and 58 the dolerite at the tunnel level is fractured and weathered.

Although narrow fracture zones, resulting from differential movement in faulting, are not detectable as such in the seismic profile, they may be inferred from significant changes in the bedrock level. A drop of 50 feet in the bedrock level between pegs 20 and 21.5 coincident with gradients in the resistivity profiles, suggests the existence of a fault. The fracture zone encountered in the tunnel below peg 20 seems to confirm this interpretation.

VI. GRAVITY SURVEY.

Principle of the Method.

In this method, variations in the force of gravity over an area are measured with a sensitive instrument called a gravimeter.

As the gravitational attraction of subsurface material depends on its density, any subsurface structures causing lateral inequalities in the density distribution will produce variations or anomalies in the gravitational force as measured at the surface.

An inherent difficulty in the interpretation of gravity observations results from the fact that any given gravity anomaly can be produced by a number of different mass distributions. Additional control by geological mapping, drilling or by using other geophysical methods is therefore required, together with a knowledge of the densities of the subsurface rocks.

In the problem of determining the thickness of relatively light sediments overlying denser basement rock, it is considered that any regional trends in the gravity values can be removed on the assumption that they arise from deep irregularities below the basement. If the density difference between the sediments and basement rock is known, the remaining gravity anomalies may be interpreted in terms of variations in the thickness of the sediments.

The unit of gravitational attraction used in this work is the milligal, which is approximately one millionth of the earth's gravitational field. The Atlas gravimeter, used in this survey, enables relative gravity values to be determined with an accuracy of ± 0.02 milligal.

Applicability of Gravitational Method in Trevallyn Tunnel Investigations.

The density of solid dolerite is approximately 2.8 gm. per cc. whereas the average density of overburden material, is estimated to be approximately 2.2 to 2.3 gm. per cc. With an assumed density contrast between solid dolerite and overburden material, the anomalies may be interpreted in terms of the variations in the depth of the dolerite below the surface. The anomalies interpreted in this way are considered to be purely local anomalies. The dolerite overlies a basement of Permian sediments and rocks of older age. As the dolerite is probably denser than the Permian sediments, the gravity values will probably show the influence of any changes in level of the base of the dolerite, such as would be caused by block faulting. It is considered however that the interpretations of this deeper structure would require a more extensive survey giving control of regional gradients, and would also require the application of terrain corrections to allow for the effects of the South Esk gorge and other topographic features.

Results.

Gravity observations were made at 100 feet intervals along the tunnel line. The observed values, to which corrections for elevation and latitude have been applied, are shown as a profile in Fig. 1, Plate No. 2.

Significant depressions in the profile (negative anomalies) indicate greater thicknesses of overburden in some places than in others.

A quantitative investigation of the negative anomaly between pegs 45 and 55 has been made by comparing it with the theoretical anomalies due to different hypothetical troughs in the dolerite. The density difference between dolerite and overburden material was assumed to be 0.6 gm. per cc. A close approximation to the observed anomaly would be produced by a trough rectangular in section (except for broadening near the surface to coincide with the seismic profiles), 400 feet wide (between 47.5 and 51.5) and extending to a depth of at least 500 feet below the surface. The trough is assumed to cross the tunnel line at right-angles. This result shows the probable dimensions of the body of low density material required to account for the observed anomaly. The tunnel level is 300 feet below the surface and it is therefore considered that unsound rock will be encountered in most of the tunnel between pegs 47.5 and 51.5, as suggested by other geophysical methods of investigation. In the inclined bore hole No. 2038, solid dolerite was cored from 151 to 277 feet along the bore, then weathered dolerite to 335 feet, where solid dolerite was again struck and continued to the end of the hole at 338 feet/

The negative anomaly extending from peg 13 to 18 was analysed in a similar manner. With the same assumed density difference, a rectangular trough, 200 feet wide (between legs 14 and 16) and 300 feet deep would produce a anomaly of approximately the same magnitude as that observed. The 200 feet length of unsound rock in the tunnel 300 feet deep indicates the probable existence of a trough similar to that postulated, and tends to confirm the validity of the interpretation method and of the assumed density difference of 0.6 gm. per cc.

The small negative anomaly of 0.4 milligal between pegs 31 and 35 is coincident with very low values of resistivity and a depression in the seismic bedrock profile. The gravity anomaly is not fully accounted for by the thickness of the overburden material as calculated from seismic measurements. It is considered that irregularly weathered zones, undetected by the seismic method, may extend to the tunnel level in this section, a result which agrees with the interpretation of the resistivity profiles.

VII. SUMMARY AND CONCLUSIONS.

Three geophysical methods of exploration, electrical seismic and gravitational, were used in a survey of the Trevallyn tunnel line to locate deeply weathered and fractured zones in the dolerite through which the tunnel is being excavated.

The principles of the methods, their application to this survey, and the interpretations of the results have been discussed in the text. Predictions of the zones of unsound rock likely to be encountered in the excavation of the tunnel from peg 23 to peg 67 are supported by the comparison of the geophysical results with known conditions of the dolerite in the length of tunnel already excavated.

Along the tunnel line between peg 48 and 5.15, resistivity seismic and gravity measurements have confirmed the existence of a deep trough of weathered material extending to tunnel level. It is considered that at least 300 feet of unsound rock will be encountered in excavating this part of the tunnel.

From peg 32 to 34, low resistivity values comparable with those over the known zones of unsound rock, a negative gravity anomaly and a depression in the seismic bedrock profile indicate deep weathering of the dolerite and it is considered that 150 to 200 feet of unsound rock is likely to be encountered at tunnel level.

Narrow zones of fracturing and weathering, believed to be associated with jointing or small scale faulting are indicated by significant gradients in the resistivity profiles at pegs 29, 39, 42 and 64, and by the sharp resistivity 'lows' centred at 57 and 61. Slight depressions in the gravity profile coincide with the resistivity indications at pegs 39, 42, 57 and 64. It is considered likely that all these narrow zones go down deep enough to affect the condition of the rock at tunnel level but the results do not provide any reliable estimate of the actual length of unsound rock at tunnel level, associated with each zone.

The results of this survey have exemplified the advantages of using several different geophysical methods in the investigation of one area. Each method needed supplementation by at least one of the others for a complete interpretation of the anomalies. Though the seismic method was the most direct method of measuring the depth to the dolerite bedrock, the jointing and irregular weathering of the dolerite tended to reduce the accuracy of the seismic results. In two places along the tunnel line, exceptionally deep weathering was indicated by the absence of refractions from solid dolerite.

The limitations of the electrical resistivity method of investigation have been mentioned in the text. However, its application, particularly with the constant electrode separation technique has proved successful in the present survey.

The gravity method needs control data, supplied by drilling or other geophysical methods, for a quantitative analysis of the observed anomalies; its purpose was most usefully served in the investigation of the two deep troughs of weathered material, where the normal refractions from solid dolerite were not recorded.

The completed excavation of the tunnel will reveal the degree of accuracy of the geophysical interpretation. The value of the survey will be greatly enhanced if eventually a comparison is made between the results of the geophysical measurements and the actual rock conditions encountered over the whole length of the tunnel. Regarded as a test of the applicability of the resistivity, seismic and gravity methods to the problem of tunnel investigation, the Trevallyn geophysical survey should be a useful guide for other tunnel investigations which may be required by the Tasmanian Hydro-Electric Commission.

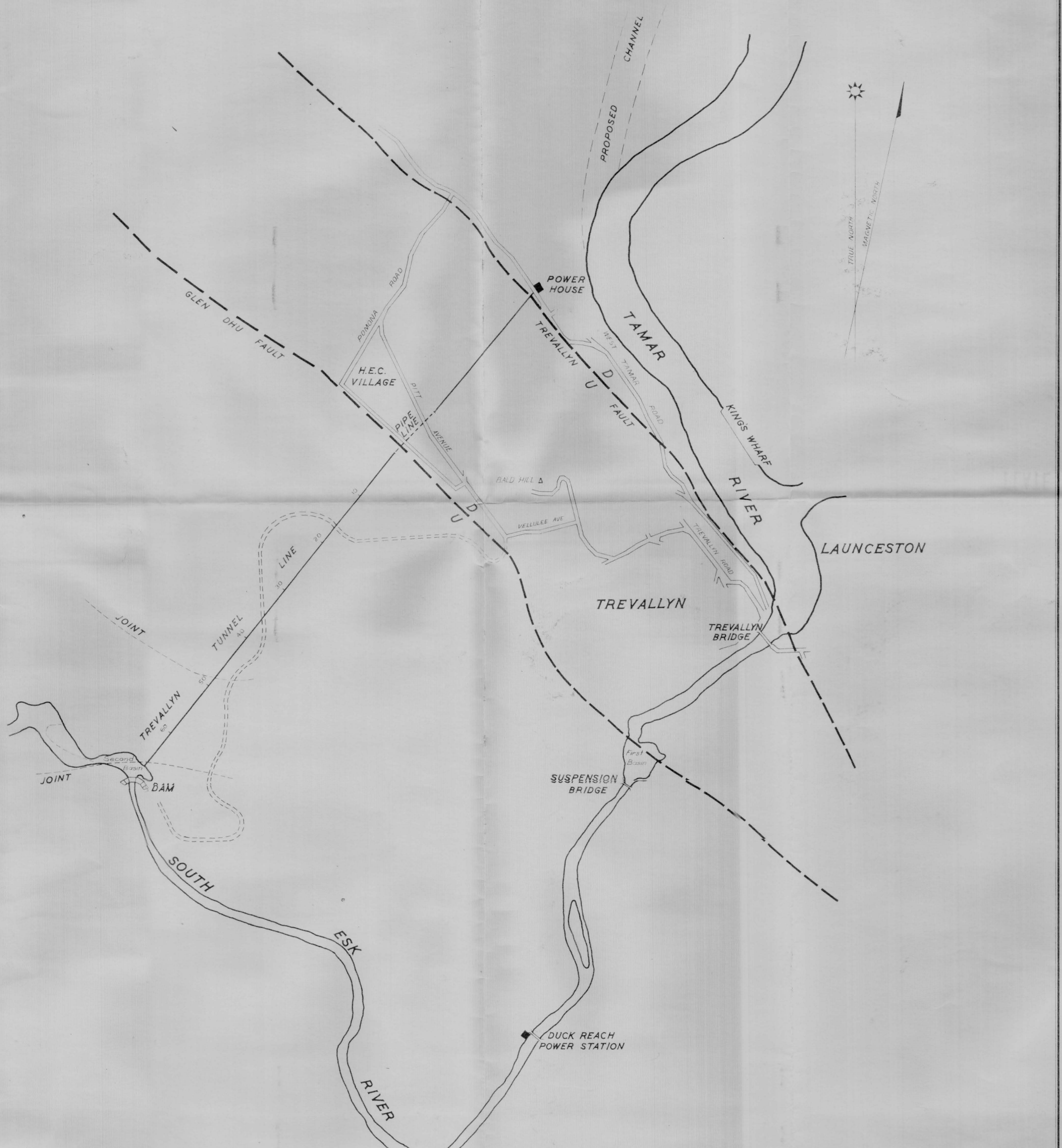
(J. H. QUILTY)
Geophysicist.

Melbourne,
October 1953.

Distribution:

1. Hydro-Electric Commission, Tasmania.
2. Chief Geologist, Canberra.
3. Geophysical Library, Melbourne.
4. " " "
5. " " "
6. " " "

PLATE I



GEOPHYSICAL SURVEY, TREVALLYN TUNNEL LINE, LAUNCESTON, TASMANIA.

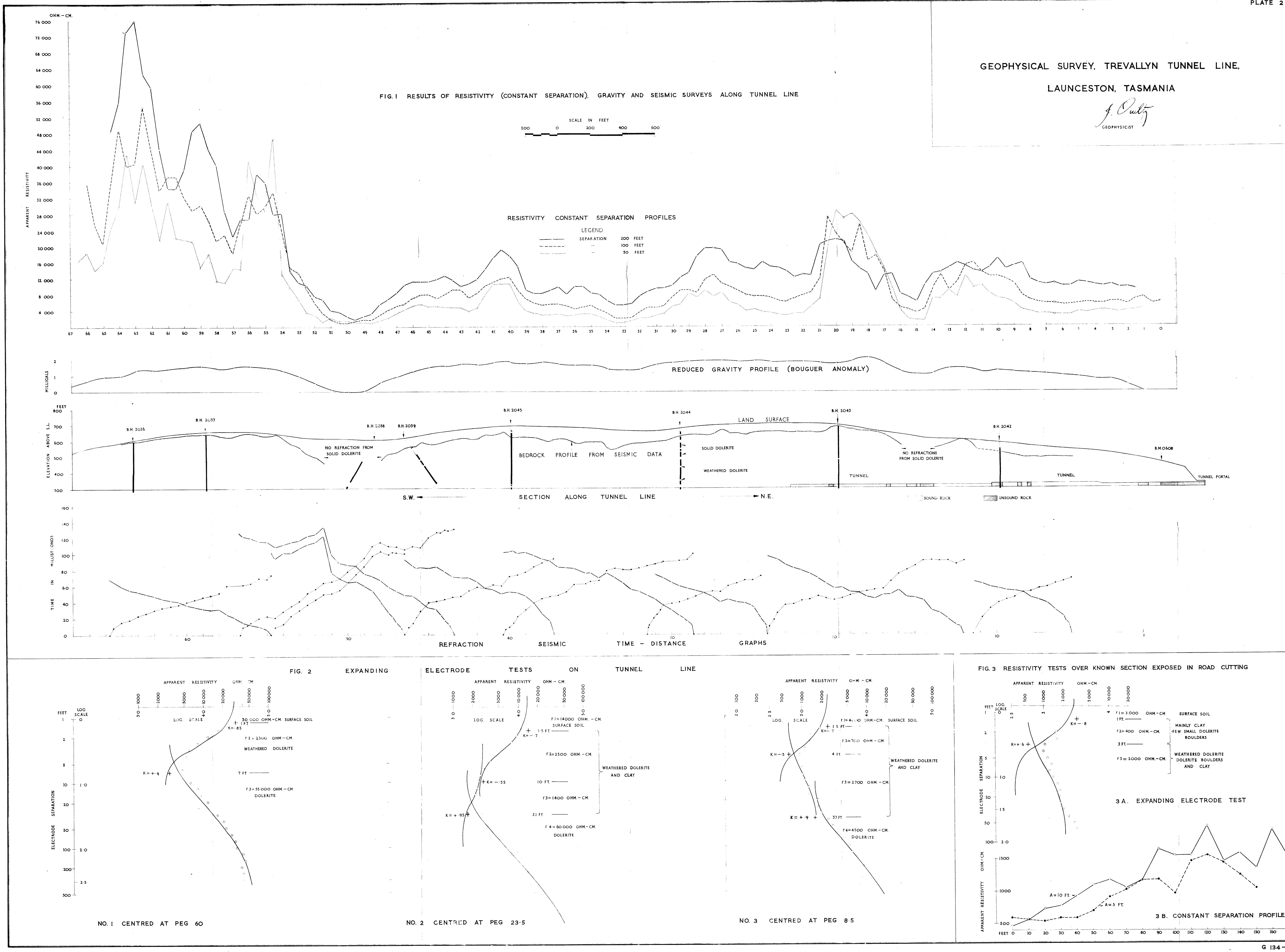
LOCALITY MAP

SCALE IN CHAINS

20 0 20 40 60

GEOPHYSICIST

PLATE 2



G 134-2