COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1964/120

LAWRENCE VALE AND HOSPITAL AREAS BOREHOLE LOGGING, LAUNCESTON,

TASMANIA

1959-60

by

W.A. WIEBENGA

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SUMMARY

CSIRO Soil Mechanics Section carried out single-point resistance and radioactive logging on shallow boreholes as part of an investigation of landslip in the Lawrence Vale and Hospital areas, Launceston, Tasmania from December 1959 to May 1960, using equipment supplied by the Bureau of Mineral Resources, Geology and Geophysics.

Clay, silt, sand, and carbonaceous sediments can be distinguished from the electrical resistance logs. The variations in salt content of the sediments could be judged from the radioactive logs because the salts contain an appreciable amount of potassium with its radioactive isotope, K^{40}. This makes it possible to distinguish leached-out clay and silt zones, and it is shown that these may probably be interpreted as potential slip zones.

In the Lawrence Vale area the beds dip about 10½ degrees west, intersect the western slope of the hill, and can easily form slip planes. The lowest boundary of possible slip is indicated. The relation between bedding planes and topography also explains why the eastern slope of the hill forms a stable zone.

In the Hospital area the beds dip about 17 degrees north, contrary to the underlying dolerite surface which slopes upward towards north. This largely explains why the Hospital area appears to form a stable zone.

1. INTRODUCTION

In recent years the Lawrence Vale hill in Launceston, Tasmania has been developed as a suburban residential area. According to local reports, evidence for landslip was noted more than 10 years ago. During the past few years landslips resulting in the destruction of houses and roads have reached such proportions that the Launceston City Council decided to ask the Soil Mechanics Section of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), headed by Dr Aitchison, to make an investigation. CSIRO drilled shallow boreholes in a restricted area but about one mile long and half-a-mile wide. The Lawrence Vale road is located on the steep western side of the hill, roughly in the centre of the area.

Further, the Health Department of Tasmania proposed to build a new hospital adjoining the existing Queen Victoria Hospital on a site, referred to as the Hospital area, nearly one mile north of Lawrence Vale. Amongst other questions related to foundation problems, it was desired to investigate the local dip and strike of the surface sediments (Polak, 1962).

To assist CSIRO in its investigation, the Bureau of Mineral Resources, Geology and Geophysics supplied a single-point resistance logger (500-ft Widco shot-hole logger), fitted with radioactive logging equipment.

The logging was done between December 1959 and May 1960 by Mr P. Kerr of the City of Launceston Engineer's drawing office. The logs were interpreted by the Bureau.

Concurrently with the drilling and logging investigation the Bureau did some geophysical survey work, mainly consisting of resistivity depth-probes (Polak, 1964).

With the logs it is possible to distinguish clay from sand or silt layers, and to obtain information about the physical nature of the sediments. The logs make it possible to correlate between boreholes and so deduce the strike and dip of the beds.

Since only one geological core log (Bore 12) was received, the interpretation is largely based on the resistance and radioactive logs and gives some very interesting and useful results. Although it is expected that a marked improvement in the interpretation would result from comparison with more geological core logs, the results show the value of logging as a tool; considerable expense and time may be saved in certain cases by using geophysical logging instead of taking a core.

2. METHODS

Single-point resistance logging.

Single-point resistance logging consists of recording variations in the resistance between the logging electrode, which is raised or lowered in the hole, and the ground electrode, which is situated at the surface. Practically the whole of the resistance in the circuit is in the immediate neighbourhood of the electrodes. As the ground electrode is stationary, the resistance in its neighbourhood may be assumed to be constant during the measurements, and the changes of resistance recorded are therefore due to variations in the resistivity of the materials around the moving electrode.

The magnitude and width of the resistance variation is controlled by the beds opposite the logging electrode, the thickness of the bed, the borehole diameter, and the resistivity of the mud. However, these factors are not linearly related to the recorded variations in resistance.

Variations in the higher ranges of resistivity have a smaller effect than similar variations in the lower ranges. The effect is to compress the resistance log for the higher ranges, and make it impossible to estimate the true resistivity from the resistance log.

The resistivity of a porous rock is inversely proportional to the porosity and the salinity of the pore solutions. Assuming that the salinity of the pore solutions remains about the same over large sections of rock, variations in the resistance log will indicate variations in porosity, and these can, with certain limitations, be translated into geological terms. For instance, clay and shale, with their high porosity, are indicated by low resistance; unsorted material of low porosity, as for instance gravel, unsorted sand, and unsorted fine sand and silt are indicated by a relatively high resistance.

Radioactive logging

Radioactive logs show variations of natural radioactivity emitted by the formations penetrated by the drill. The following is a list of sedimentary rocks in decreasing order of radioactive intensity:

organic clay and shale
clay and shale
shaly fine sand and silt
shaly sandstone
shaly limestone
sandstone
limestone
dolomite
salt
coal

Since clay and shale are generally more radioactive than sand (including fine sand and silt), the radioactive log variations often correspond to lithological changes in a manner contrary to the variations in the resistance log. The response of the radioactive probe is also affected by absorption, and varies with the diameter of the hole, the density of the drilling fluid, the casing thickness, and the degree of saturation of the ground. These conditions have to be taken into account for interpretation; and corrections have to be applied for quantitative interpretation.

3. GEOLOGY AND INTERPRETATION

Geology

It was reported by the Curator of Fossils, National Museum of Victoria (Gill, pers. comm.), who examined the drill cores, that the top of the Lawrence Vale hill is capped by 30 to 40 ft of weathered greywacke sandstone, overlying a formation of clay, silt, and fine sand. The latter formation consists of alternate layers of carbonaceous and non-carbonaceous sediments. At the base of the sediments is dolerite. Faults and slip zones are common. A brief statement of the geology is given by Gill (1962).

The groundwater is partly saline (salinity up to 6000 p.p.m.) and contains, apart from magnesium and sodium, up to 20 p.p.m. of potassium and traces of nickel. The potassium -40 isotope is radioactive. As clay is a good absorber of potassium ions (and other metal ions), it seems likely, or at least possible, that the radioactivity of the Lawrence Vale clay is caused by potassium which is also present in the groundwater.

The traces of nickel in the groundwater suggest that part of the water may come from or through dolerite, or weathered products of dolerite e.g. the greywackes.

The saline and fresh groundwaters are irregularly distributed through the whole vertical section. This pattern of intermingled fresh and saline waters suggests that:

(a) Either the original sediments were deposited in a saline or brackish water environment, or the salinity of the groundwaters increased by progressive weathering.

(b) Saline waters ascending from the dolerite are superimposed on the original groundwater (indicated by the presence of 'nickel' traces).

(c) Fresh rain-water soaking into the hill intermingles with saline water, and probably leaches out the sediments, including the salt contained in clay and silt, by a process of ion-exchange.

Interpretation rules

Baver (1940) showed that the hydration characteristics (and also the viscosity) of clay are dependent on the metal ions, including potassium, commonly found in salt water. Bjerrum (1954) has conclusively proved that the shear strength of saline clay is considerably lowered by leaching; he uses his data and experiments for the explanation of landslips in Norway.

The above shows that the salt content of the clay may give an indication of the probable occurrence of landslips, whatever the original source of the salt in the clay may be. It seems possible that leached-out clay zones at Lawrence Vale hill could be identified as major (potential) slip zones. At least, this possibility could be used as a working hypothesis.

On the logs, clay shows a low resistance because of its high porosity, and a relatively high radioactivity because of its capacity to absorb potassium. However, if during long time intervals the clay is leached out by fresh rain-water, the radioactivity could be appreciably lowered. Although the resistivity of the clay would increase with leaching, it would remain lower than that of unsorted sands because of the high porosity of clay. Hence, leached-out dlay zones, possibly corresponding to slip zones or potential slip zones, are indicated on the logs by low resistances and low radioactivity.

Carbonaceous clay and silt usually show a much higher radioactivity than corresponding non-carbonaceous clay.

Sand, and to a lesser degree silt, because they usually consist of less-sorted material and contain less potassium, show a higher resistance and a low radioactivity.

Dense rocks of low porosity (e.g. coal or crystallised limestone) usually are recognised by resistance peaks.

4. LAWRENCE VALE AREA

Plate 2 shows the layout of the bores, Plates 3 and 4 an interpretation of the logs as cross-sections through bores, Plate 5 the relation of bedding planes to topography, and Plate 6 the results and their relation to the slip areas in the form of a plan.

The vertical depth scales of the logs are shown as altitudes above to a common datum, viz. mean sea level. These altitudes are used in the following discussion.

The sediments consist of thinly interbedded layers of clay, silt, and sand. On the cross-sections the predominant rock types as interpreted from the logs are indicated.

Discussion of logs

Bore 5

The main discontinuity is at about 209 ft. The resistance log indicates sand and silt above this level and clay below this level.

The radioactive log is irregular below 209 ft and this may be caused by carbonaceous sand and silt. A high-resistance feature between 236 and 252 ft, partly overlapping a radioactive feature, suggests the presence of carbonaceous sand or silt. Between 252 and 279 ft the radioactivity is low, as is normal for sand and silt; but in the clay close to the surface the radioactivity is high.

The clay formation below 209 ft shows a jagged resistance curve, indicative either of alternating layers of carbonaceous and non-carbonaceous material, or of alternating thin layers of clay and silt.

From 209 to 179 ft the low radioactivity indicates a leached-out clay, possibly a major slip zone; below 179 ft the radioactivity is greater.

When the drill pipe was pulled out, clay was extruded into the hole just below 179 ft, preventing the logging probe from passing unhindered. This conclusively proved that the clay was plastic.

Bore 6

The resistance log of Bore 6 shows essentially the same features as the one of Bore 5; below 234 ft there is only clay, but above 234 ft there are sand, silt, and clay. The zone of low resistivity between 252 and 268 ft in Bore 5 has been correlated with a zone in Bore 6 between 282 and 296 ft. The clay of low resistivity lying above the 277-ft level in Bore 5 is correlated with that above 305 ft in Bore 6.

The radioactive log of Bore 6 does not show the same large radioactive features as the log of Bore 5, probably because of leaching by fresh rain-water.

The top clay formation above 305 ft shows a large radioactive feature. Between 305 and 236 ft the radioactive features probably correspond to silt and clay layers which may be carbonaceous.

Below 236 ft the lower radioactivity suggests a leached clay zone, which may represent a slip zone.

Except for the clay near the surface, the sediments at Bore 6 seem to have been leached out far more than at Bore 5. This suggests that potential slip zones are more likely to be found near Bore 6 than near Bore 5.

Bore 7

The resistance log of Bore 7 is recorded close to the side of the recording paper, and so shows the features at a compressed scale.

Although the correlation of resistance features with Bore 6 is difficult, an approximate correlation was made by using radioactive features. The correlation is shown in Plate 3.

Resistance peaks at 305 and 313 ft are accompanied by radioactive anomalies which suggest that they are due to carbonaceous silt or clayey sand. From about 309 ft to the surface the logs suggest the presence of radioactive clay.

Compared with Bore 9 the resistance log indicates very little carbonaceous material. The radioactive anomalies are well-defined, and suggest practically no leaching except from the bottom (169 ft) to 186 ft, and possibly between 271 and 284 ft. Field evidence shows that Bore 7 is located in a relatively stable area.

Bore 9

Although the correlation between Bores 9 and 7 is hardly possible the correlation between Bores 9 and 6 is easier; resistance features above 218 ft in Bore 6 resemble resistance features above 232 ft in Bore 9.

The resistance curve of the portions of the bore between 225 and 273 ft, and between 125 and 177 ft shows a very jagged form, probably caused by alternating layers of carbonaceous and non-carbonaceous material.

The radioactive log is featureless in the upper part of the bore; the first small features appear below 210 ft. As explained in Section 3 this indicates that the top portion is completely leached out, and the lower portion is partly leached out. The bore is therefore probably located in a bad slip zone. Field evidence shows that Bore 9 is in or close to the worst landslip zone in the area.

It is not known whether carbonaceous layers promote landslip, but the presence of many thin layers of carbonaceous material in the worst part of the landslip area rather suggests this possibility.

Bore 4A

From 240 ft down to 120 ft the resistance log shows a gradual increase, which indicates an increase in silty or sandy material. Below 60 ft the resistance drops again, probably because of an increase in clay.

The near-surface clay is highly radioactive, but radioactivity decreases below the 200-ft level; a sudden drop at 152 ft suggests the presence of a leached-out zone. Between 116 and 144 ft the radioactive log is not satisfactorily recorded. Below 116 ft the radioactivity is higher again and then increases further in the lower clay formation below 32 ft. In some places local increases in radioactivity correlate with local increases in resistance, e.g. at 168, 156, 52, 24, and 8 ft. This suggests the presence of carbonaceous silts at these levels.

Bore 3

The resistance curve of Bore 3 shows a remarkable resemblance to that of Bore 4A.

For instance, the resistance increases gradually from 229 to 149 ft, indicating an increase in silty or sandy material. Small resistance features at 207, 187, 147, and 108 ft can be correlated with features of the log of Bore 4A at 180, 158, 119, and 80 ft indicating that the sediments at Bore 3 are about 28 ft higher in level than at Bore 4A. It is noteworthy that the surface elevation at Bore 3 is also about the same amount (29 ft) higher than at Bore 4A, suggesting that the sediments in this area are approximately parallel to the land surface.

A comparison between the radioactive logs at Bore 3 and Bore 4 A shows one remarkable difference, viz. between 234 and 187 ft the radioactivity in Bore 3 is very much lower than on the corresponding place in Bore 4A, suggesting a large leached-out slip zone in Bore 3.

The pattern of logs of Bores 3 and 4A is quite different from those of Bores 5, 6, 7, and 9. Only a rough correlation could be made between these two groups.

Bore 13

A strongly radioactive clay layer is located between the surface and 182 ft.

The resistance log indicates sand or silt layers interbedded with radioactive clay layers. Two zones at 122 and 176 ft, distinguished both by low resistances and low radioactivity, are interpreted as leached-out zones.

High-resistance peaks, which may possibly be caused by carbonaceous layers, are common throughout the cross-section.

An approximate correlation with Bore 4A was made.

Bore 10

The resistance log shows alternating layers of clay and silt or sand above 24 ft. Possibly quite a number of the high-resistance peaks represent carbonaceous material. Below the range 24-39 ft below sea level, the formation consists mainly of clay. The gamma-ray log suggests the presence of leached zones. The correlation with neighbouring Bore 13 is uncertain.

Bore 8

This bore was not logged.

Results

Plates 3 and 4 show the interpretation and correlation of the logs in diagrammatic cross-section.

Plate 6 shows the location of a fictitious bedding plane through depth zero of Bore 7, indicated by dashed contour lines, and constructed from the cross-section of Plates 3 and 4.

Plate 5 shows the relation of bedding planes to topography, illustrated by cross-sections. The bedding planes appear to be sub-parallel to parts of the western slope of Lawrence Vale hill. The average dip is about $10\frac{1}{2}$ degrees towards west. If the bedding planes serve as slip planes, which seems possible considering the nature of the clay beds, parts of Lawrence Vale hill may slip towards the west. On Plate 5 the lowest boundary of possible slip is indicated by lines through X1, ... , X5. This is taken as the place where the dipping layers are approximately tangential to the surface.

On Plate 6 the intersection of the above-mentioned fictitious bedding plane through surface at Bore 7 with the ground surface is indicated by a dash-dot line. Also, a shaded broken line through the plotted points X1, ... , X5 (obtained from Plate 5) indicates the lowest boundary of possible slip along a bedding plane.

5. HOSPITAL AREA

A group of five bores (see Plate 1) was logged and the logs were correlated in a similar way to the Lawrence Vale bore logs. A geological core log was received for Bore 12. Plate 3 shows the correlation of three of the five bore logs.

To compute the dip of the surface sediments a topographical sketch plan was made and the position of a marker bed (68-ft elevation at Bore 12) was indicated by elevation contours. It was found that the sediments dip about 17 degrees in the direction six degrees east of north.

A seismic survey (Polak, 1962) showed that near Bore 12 the dolerite is about 30 ft below sea level. The logs of Bore 12 show generally higher resistance values and very low radioactivity below 34 ft below sea level, possibly confirming the presence of weathered dolerite. The seismic survey also showed that the dolerite surface slopes upward towards north. This explains why the overlying sediments with a downward slope towards north show no evidence of landslip, and indicates that they probably will not slip under load.

Although the distance between the Hospital area bores and the Lawrence Vale bores is nearly one mile, it was possible to correlate between the two groups. A high-resistance marker at 210 ft in Bore 5 overlying a leached-out plastic clay, corresponds with a similar feature at 114 ft in Bore 16, and at 91 ft in Bore 12.

6. CONCLUSIONS

The combination of radioactive logging and single-point resistance logging was found to be effective in the study of the landslip problem.

The radioactive log indicates the variation in salt (potassium) content of the sediments. The results of the survey show that in the known landslip zones the salt content of the clay sediments has been largely or entirely leached out, e.g. the log of Bore 9, which is located in or close to the worst landslip zone of the area, shows a conspicuous lack of radioactive anomalies from the surface down to a reduced level of 210 ft.

Therefore, it is considered that any place where the salt content has been leached out of the clay sediments should be regarded as a potential landslip zone.

In Plates 3 and 4 corresponding features of resistance logs of the different bores are connected by dashed lines. In the Lawrence Vale area the leached zones form a regular pattern, which is also illustrated by Cross-section A-B of Plate 5.

In the Lawrence Vale area the smoothness of the contours of a fictitious bedding plane (Plate 6) suggests that no important faults are present in the upper beds, and that the beds dip about $10\frac{1}{2}$ degrees westwards. The dipping clay beds may easily serve as slip planes where they intersect the ground surface. The lowest boundary of possible slip (Plate 6) is indicated. It is significant that the worst landslip places are located east of and above this boundary on the western slope of the hill. The relation between bedding planes and topography (Plate 5) also explains why the eastern side of Lawrence Vale hill forms a stable zone.

In the Hospital area the contours on a marker bed showed that the sediments dip about 17 degrees northwards. A seismic survey has shown that the dolerite surface at a depth of about 30 ft below sea level showed locally an upward slope towards north. This relation between dolerite surface and dipping bedding planes largely explains why this area appears to form a stable zone.

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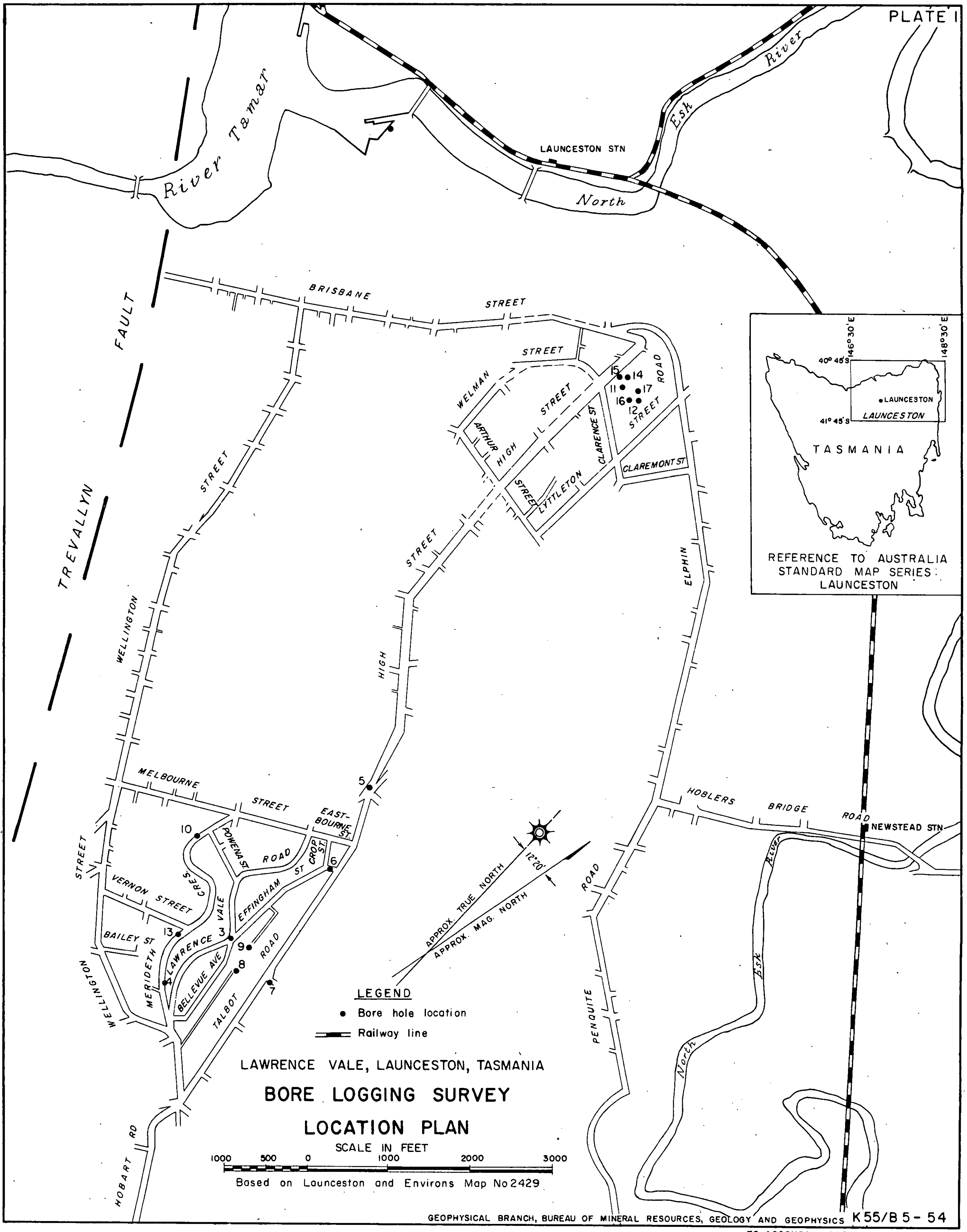

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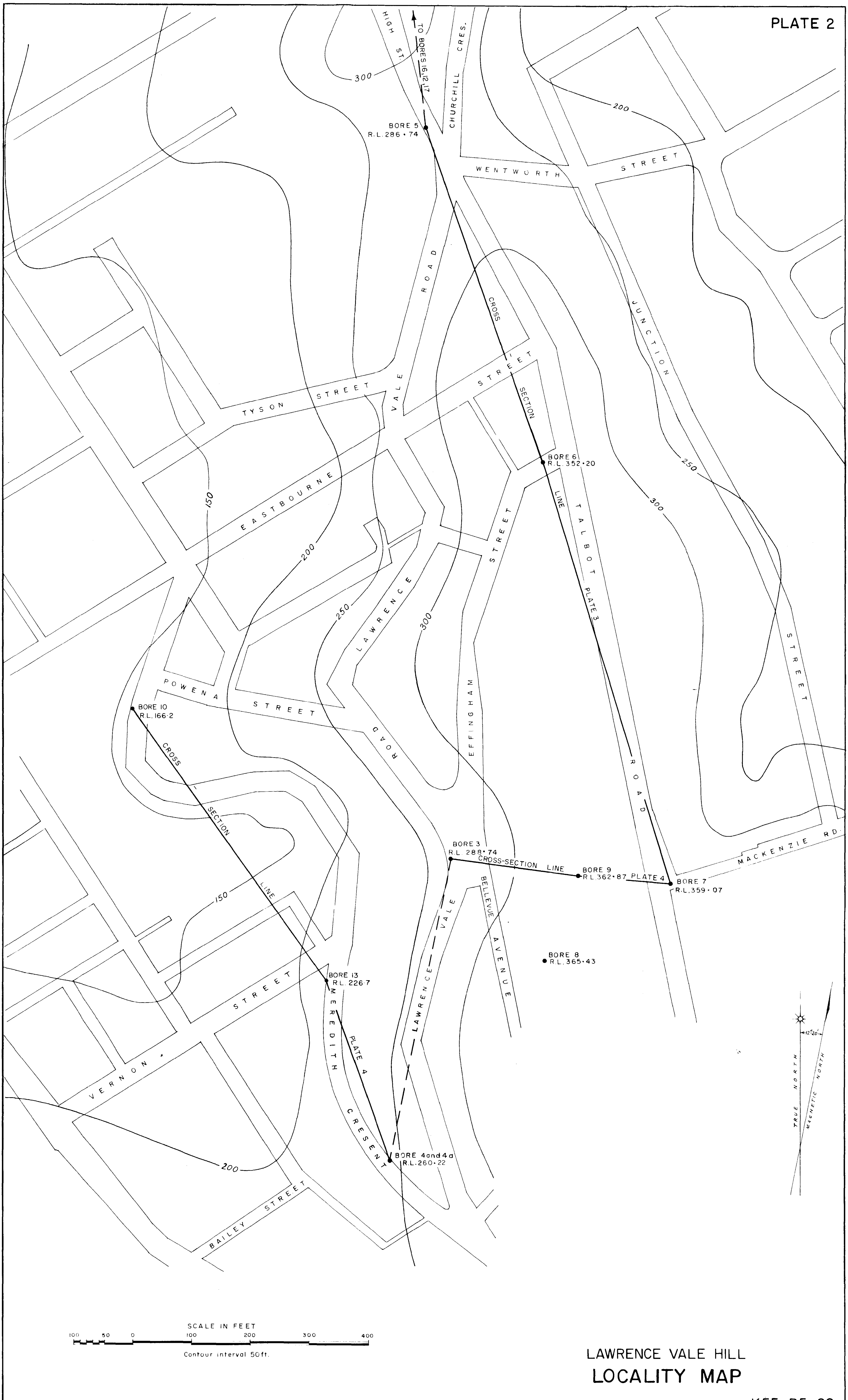
LAWRENCE VALE, LAUNCESTON, TAS.



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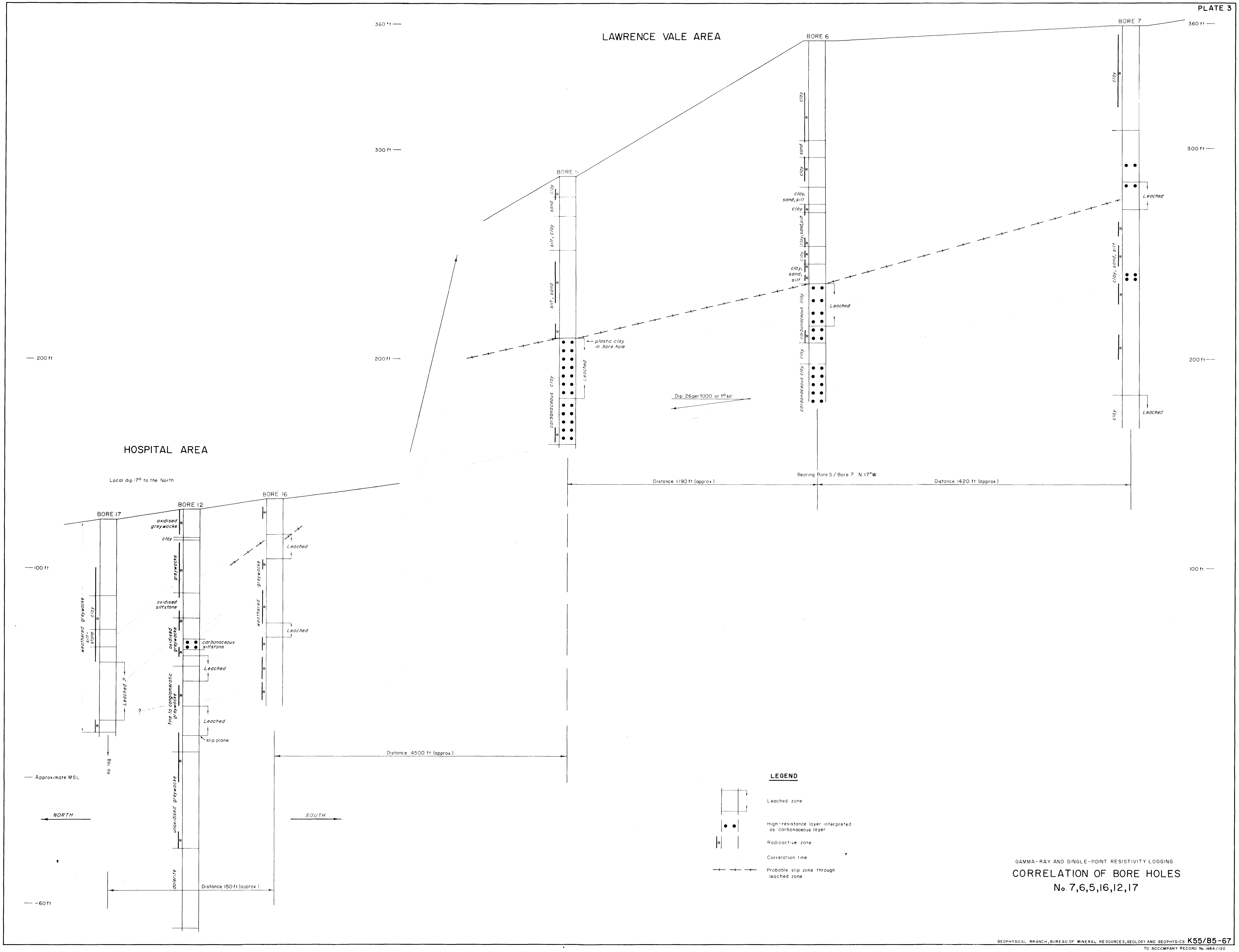

PLATE 3
LAWRENCE VALE AREA
BORE 5
BORE 6
BORE 7
360 ft
300 ft
200 ft
100 ft
clay
sand
silt, clay
silt, sand
carbonaceous clay
plastic clay in bore hole
Leached
clay, sand, silt
Dip: 26 per 1000 or 1°30'
Distance 1190 ft (approx)
Bearing Bore 5 / Bore 7 N 17°W
Distance 1420 ft (approx)
HOSPITAL AREA
Local dip 17° to the North
BORE 17
BORE 12
BORE 16
oxidised greywacke
greywacke
oxidised siltstone
carbonaceous siltstone
fine to conglomeratic greywacke
slip plane
unoxidised greywacke
dolerite
weathered greywacke
silt-stone
Leached ?
no log
Distance 4500 ft (approx)
Distance 150 ft (approx)
Approximate MSL
-60 ft
NORTH
SOUTH
LEGEND
Leached zone
High-resistance layer interpreted as carbonaceous layer
Radioactive zone
Correlation line
Probable slip zone through leached zone
GAMMA-RAY AND SINGLE-POINT RESISTIVITY LOGGING
CORRELATION OF BORE HOLES
No. 7,6,5,16,12,17
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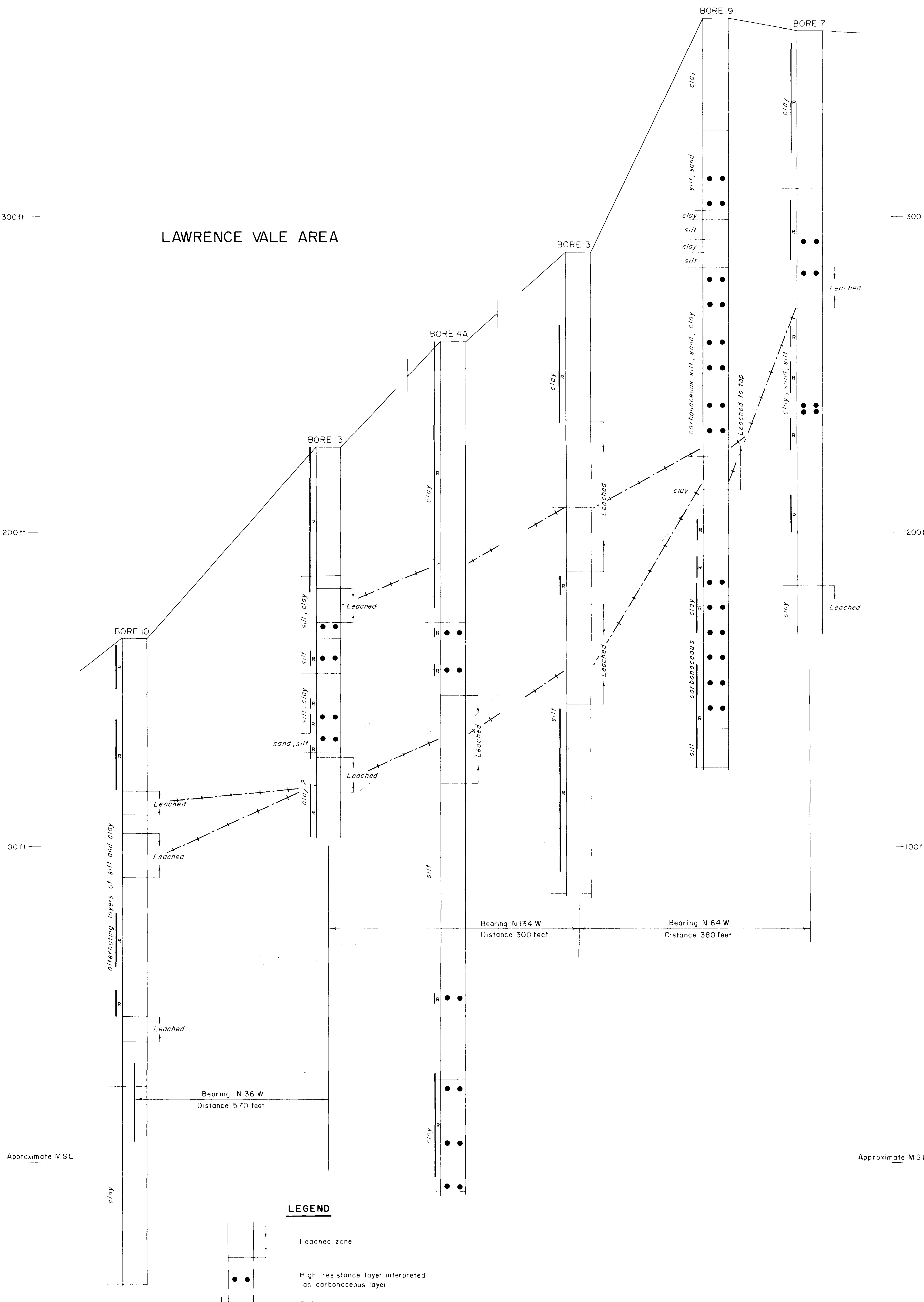
PLATE 4



GAMMA-RAY AND SINGLE-POINT RESISTIVITY LOGGING

CORRELATION OF BORE HOLES

No. 7,9,3,4A,13,10

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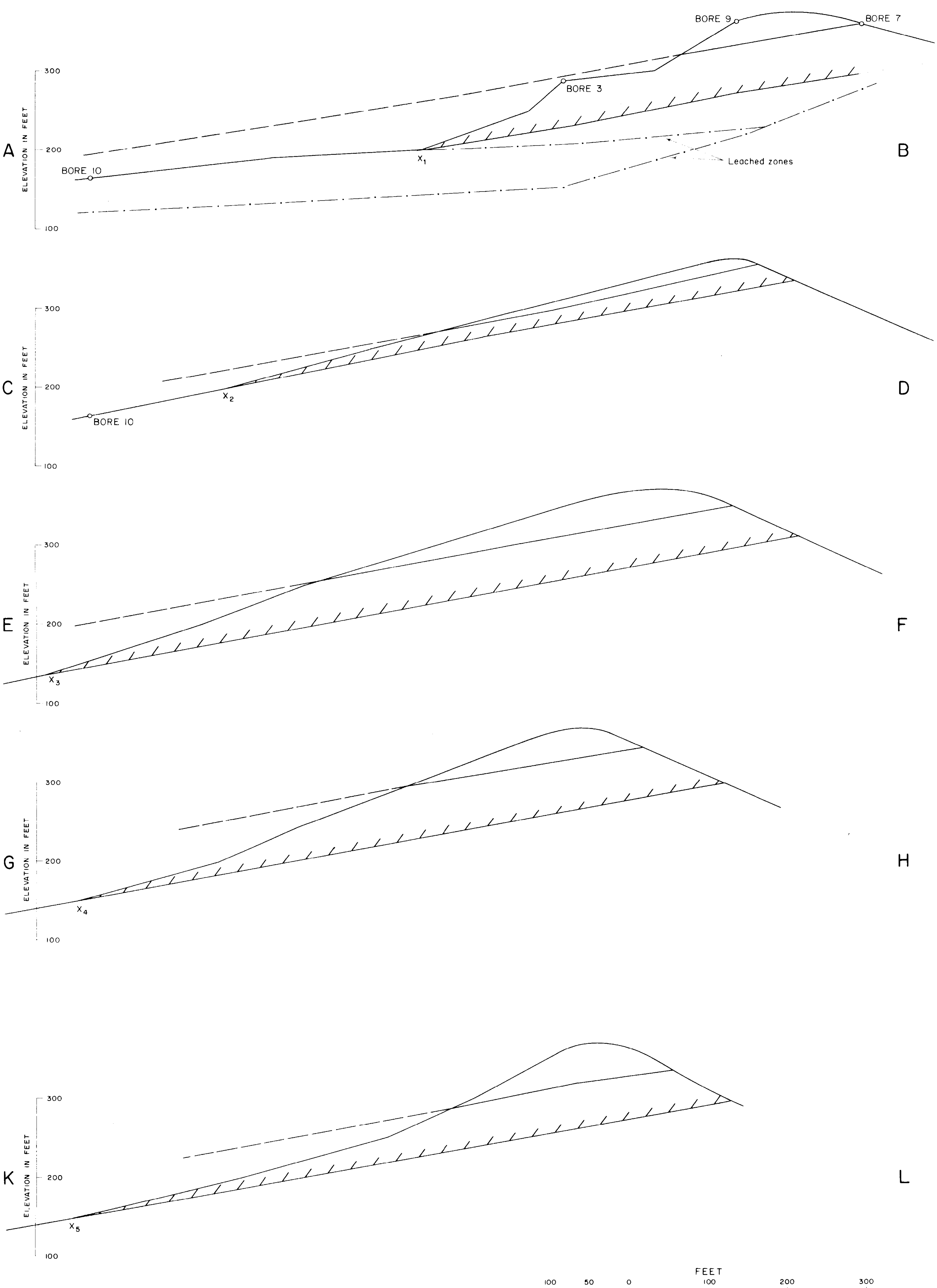
PLATE 5



LEGEND

Bedding plane

Lowest boundary of possible slip along bedding plane

GAMMA-RAY AND SINGLE-POINT RESISTIVITY LOGGING

CROSS-SECTIONS SHOWING RELATION BETWEEN BEDDING PLANES AND TOPOGRAPHY, LAWRENCE VALE AREA

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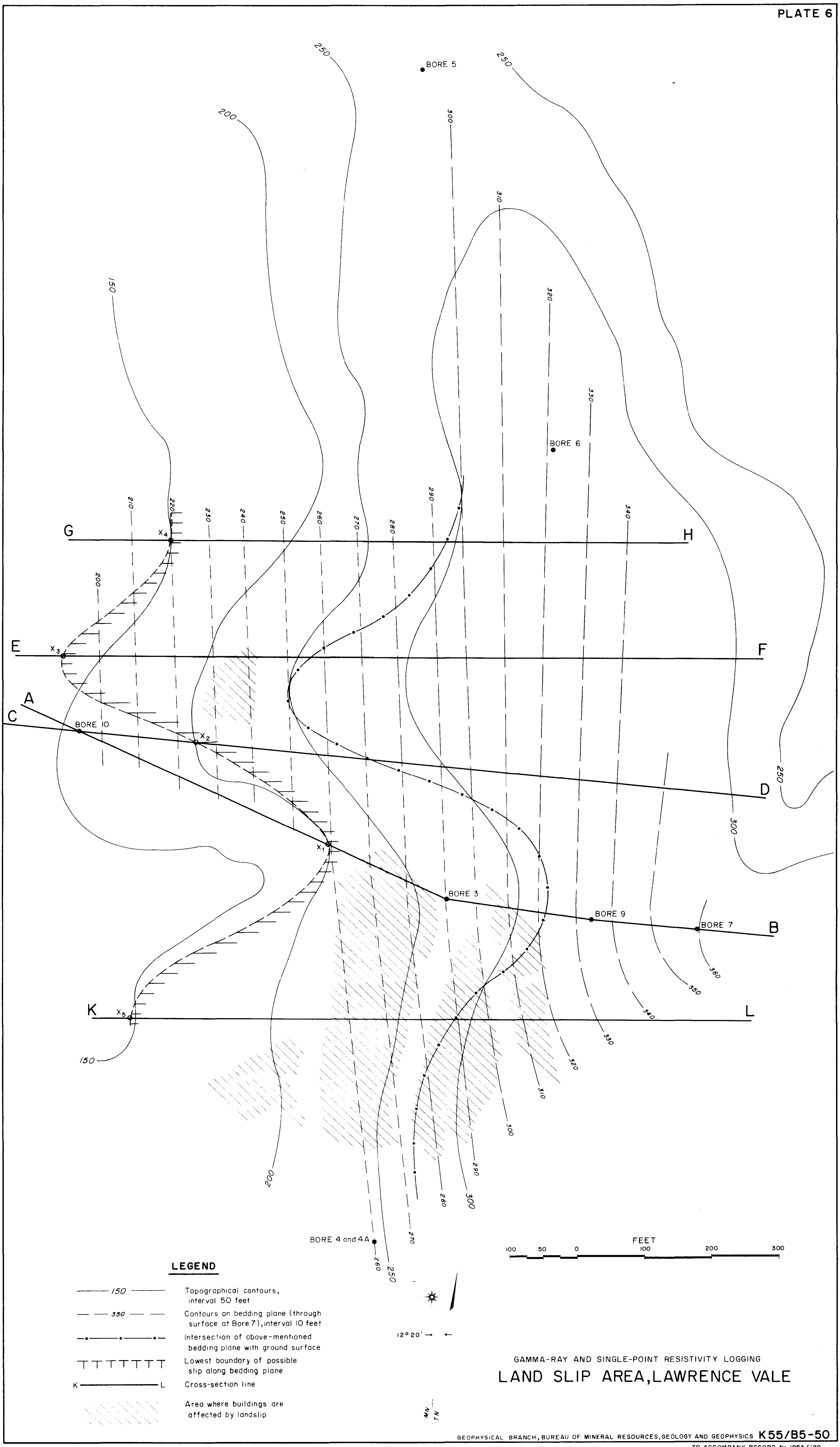

GAMMA-RAY AND SINGLE-POINT RESISTIVITY LOGGING

LAND SLIP AREA, LAWRENCE VALE

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS K55/B5-50

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