# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# RECORD

BMR RECORD 1981/35

## STABILITY ANALYSIS OF THE SOUTHWESTERN SLOPE OF TUGGERANONG HILL, ACT, 1977

by

L.F. Macias

BMR RECORD 1981/35

# STABILITY ANALYSIS OF THE SOUTHWESTERN SLOPE OF TUGGERANONG HILL, ACT, 1977

by

L.F. Macias

CONTENTS

FIGURES

## ABSTRACT

Analysis of the joints on Tuggeranong Hill indicates that there are three main and five minor sets of joints. Slope stability was assessed from joint stereograms of four selected slopes, two of which were in a zone from which past rockslides had originated.

It was concluded that isolated joint blocks on the upper slopes were in danger of toppling, and consituted a hazard to safety; some blocks could be barred down, but toppling of other blocks is to be expected in the longer term.

Kinetic block and wedge failures may be expected on slopes above 32-37 degrees. The failures could be initiated by earthquakes, excessive moisture in the slopes, or frost action associated with a cooler climate.

Urban development of the footslopes does not seem appropriate as block and wedge failures consitute a risk to life and property. Nothing short of major engineering could improve the stability of the hillslope, and this would probably place the costs of development prohibitively high.

The hillslopes and footslopes will have to withstand the ravages of toppling blocks and probably rockslides. It is expected that forest regeneration in both areas would reduce the extent of such damage. Some restriction of access to the hillslope should also be considered to prevent the deliberated toppling of boulders downslope.

## INTRODUCTION

Tuggeranong Hill is located about 18 km south of Canberra and east of the junction of Tharwa Road with Point Hut Road (Fig. 1). If forms part of the western margin of Tuggeranong Valley where urban development is in progress.

Tuggeranong Hill rises 243 m above the gently sloping pediment of the north Lanyon basin, and is 858 m above sea level, (Plate 1). The hill is elongated to the northwest and the surrounding slopes average about 25 degrees; however, the southwestern slope is much steeper, and averages about 45 degrees on the steeper slopes and about 32 degrees elsewhere. Slope angles measured during the investigation ranges to 59 degrees.

Whilst carrying out work on colluvial deposits in the north Lanyon basin in Tuggeranong, J.R. Kellett noticed lines of boulders across the pediment at the foot of the hill on a slope of between 5 and 10 degrees (Fig. 2). The boulders are part of chaotic rockslide deposits that extend for over 500 m across the south western pediment at the foot of the hill. On examining the upper slopes of the hill from where the rockslide would have been initiated, Kellett found much steeper slopes, and recognised many joints unfavourably oriented for slope stability. A number of large boulders appeared to be in danger of rolling downslope (Fig. 3).

An earlier geological report on the Tuggeranong area (Jacobson and others, 1976) had been prepared for the National Capital development Commission (NCDC) for use in urban planning and development of the area, but the report did not identify the rockslide deposits on the footslope. As the footslope had been set aside for urban development, the NCDC was informed of Kellett's observations of the possible disadvantages of development on the rockslide deposits, and of the possibility of boulders being dislodged from the upper slopes of the hill. An investigation of the area was recommended by BMR and was carried out in the latter part of 1977 at the request of NCDC.

## GEOLOGY

The geology of Tuggeranong Hill has been described by Mendum (1975) and by Jacobson and others (1975, 1976); additional work was carried out by Kellett (in prep.) in his investigation of the drainage problems at Lanyon.

Tuggeranong Hill consists of welded tuff of dacitic to rhyodacitic composition that unconformably overlies steeply folded Silurian rocks. The welded tuff is regarded as Silurian to Devonian in age, and is shown with the symbol S-Dv on Plate 1. Kellett (in prep.) describes the formation over the wider area of Lanyon as blue-grey and purple porphyritic rhyodacite containing sandstone interbeds. The welded tuff is generally dark, hard, massive, and slightly weathered in outcrop. It contains phenocrysts up to 10 mm across

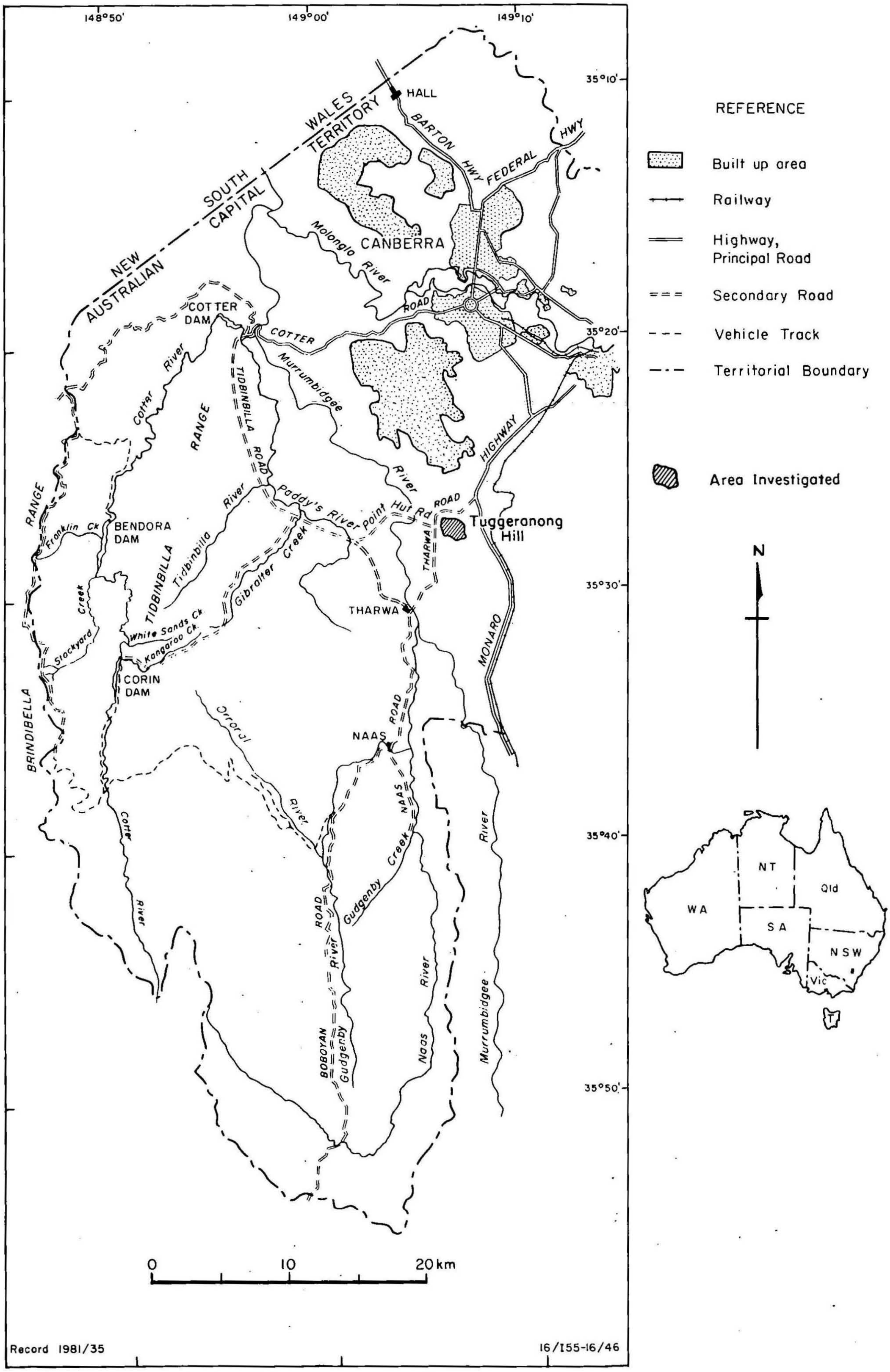



Fig. 1 Locality map

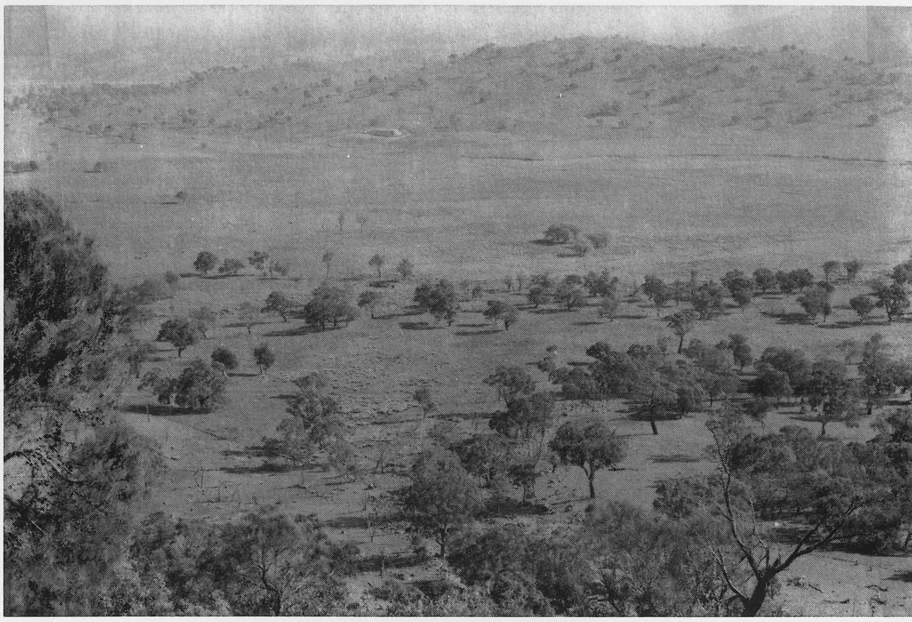


Fig. 2 Looking southwest from Tuggeranong Hill across the north Lanyon basin. The lower pediment at the foot of the slope extends to the grasslands and supports some scattered trees. Boulders in the centre foreground are the remnants of a rockslide. BMR Neg. # M2244, frame 8.

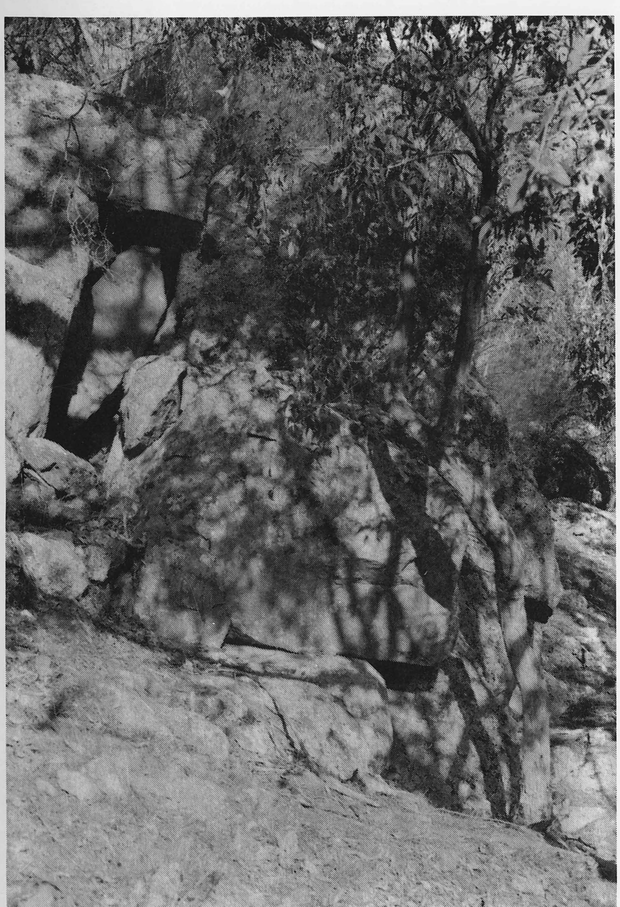


Fig. 3 Steeply-dipping intersecting joints form wedges that open up joints. Flat-lying joints at the base of boulders on the southwestern slope of Tuggeranong Hill.
BMR Neg. # M2244, frame 13

16/I55-16/70

Fig. 4 Boulder lines in a rockslide deposit exposed by removal of finer material by outwash in gullies on the southwestern footslopes of Tuggeranong Hill. BMR Neg. #M2244, frame 3 and 4.

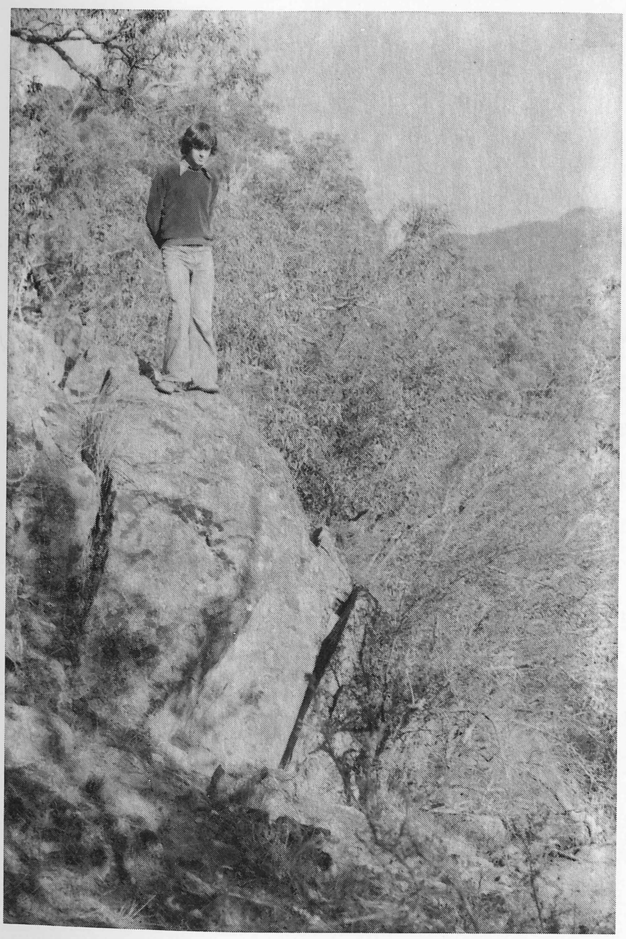


Fig 5 Steep southwestern slope of Tuggeranong Hill showing open vertical joints. As the joints open up, the boulder will eventually become unstable and topple down the slope. BMR Neg. #M2244, frame 18.

of quartz, and pink orthoclase in a dark-grey to purple or blue-grey groundmass. The tuff has a general north-south trend and a sub-horizontal dip, generally visible as banding in the tuff.

The middle and upper slopes are covered with skeletal soil (Qa) and boulders. The boulders are generally 0.3 - 0.6 m across, although some range to 3.0 m across (Fig. 5).

The lower slopes consist of a polymict colluvium with boulders and rock debris (Czp). Kellett 1980, (pers. comm.) describes the colluvium, exposed in an observation pit (shown in Plate 1), as follows:

| | |
|---|---|
| 0.0 - 0.45 m | Pale grey silty colluvium; matrix comprises mainly silt to fine sand size material; structure is open, and clasts occur as: (i) 1 - 5 mm crystal fragments disseminated throughout: and (ii) 10 - 40 cm angular volcanic rock concentrated in the lower 20 cm. |
| 0.45 - 0.85 m | Tuggeranong clay; olive-yellow plastic clay. |

The upper part of the pit exposure is thought to be part of a rockslide that became detached from the upper slopes of Tuggeranong Hill, and spread out across the valley on top of the Tuggeranong Clay, one of the sedimentary units of the north Lanyon basin. This rock debris has been mapped as colluvium (Czp - see Plate 1); the base of the colluvium is expected to be gently undulating, and its thickness is likely to range to two or more metres.

The lines of boulders (Fig. 4) in linear arrangement are lag deposits from which the finer material has been washed out as water runs off across the footslope. The boulders are generally 0.8 - 1.2 m across, and exceptionally 3 - 4 m across.

The soil profile on the colluvium is considered to be part of the Gigerline Pedoderm, as defined by Kellett (in prep), which is correlated with the $K_2$ soil of van Dijk (1959). The $K_2$ soil is from 2000 - 5000 years old. Deposition of the colluvium as debris from one or more rockslides would have taken place immediately prior to the process of soil formation; it would be regarded as a relatively recent happening within the geological time scale. The climate was post-glacial, but the colluvium has not been dated with the precision necessary to speculate upon the climate that might have prevailed at the time of deposition.

## STRUCTURE

### LINEAMENTS

Aerial photographs of the area indicate several lineaments or fracture elements (Plate 1). A rose diagram (Fig. 6) shows the preferential directions of the photo-lineaments, namely 022° - 032° and 109° - 122°.

### JOINTS

Joint spacing in the welded tuff is generally from 0.1 to 1.1 m. The joints are clean, tight, and generally quite strong, as demonstrated by the many unbroken but jointed boulders up to 3 m across that are exposed in the rockslide deposits on the lower pediment slopes.

Eighty-one joint attitudes were recorded during the investigation. The directions of the joints were plotted as a rose-diagram (Fig. 7); these are two main directions, 090° - 110° and 150° - 170°, and secondary directions 000° - 020°, 030° - 045°, and 060°. Histograms in Figure 8 show the variation in azimuth of joints comprising the main and secondary joint seta.

### CONSTRUCTION OF STEREOGRAMS

The poles of the joints were plotted on an equatorial stereonet constructed by the Lambert equal area projection. The density of poles on the stereonet was contoured, and showed three major and five minor areas of pole concentration (Fig. 9). Each area of pole concentration represents a set of joints, and a central point in each area of concentration was selected as the pole representing the particular joint set.

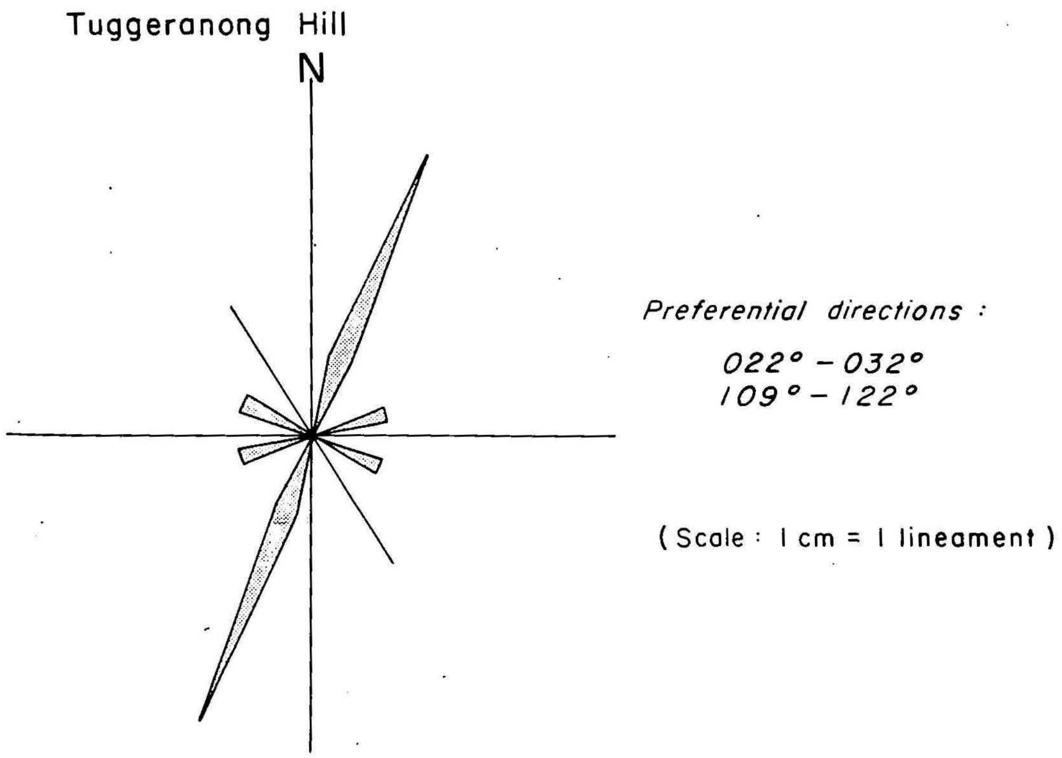
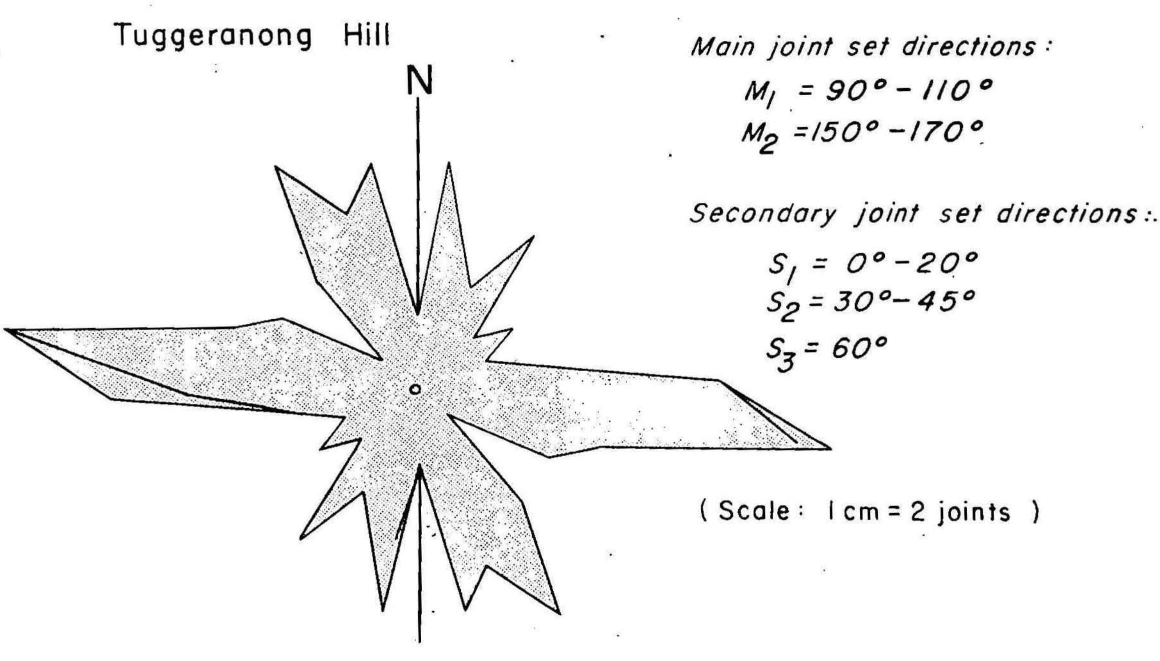


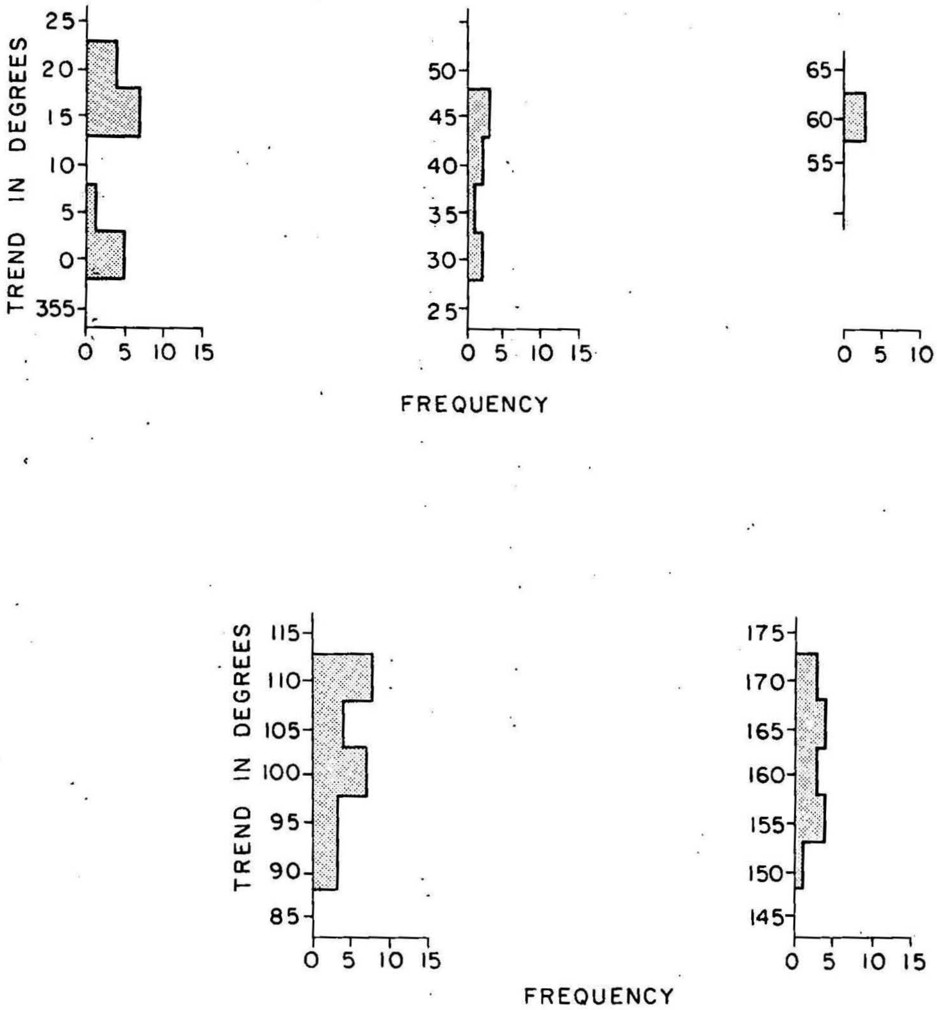

Fig 6 Rose diagram showing preferential directions of photo-lineaments




Record 1981/35

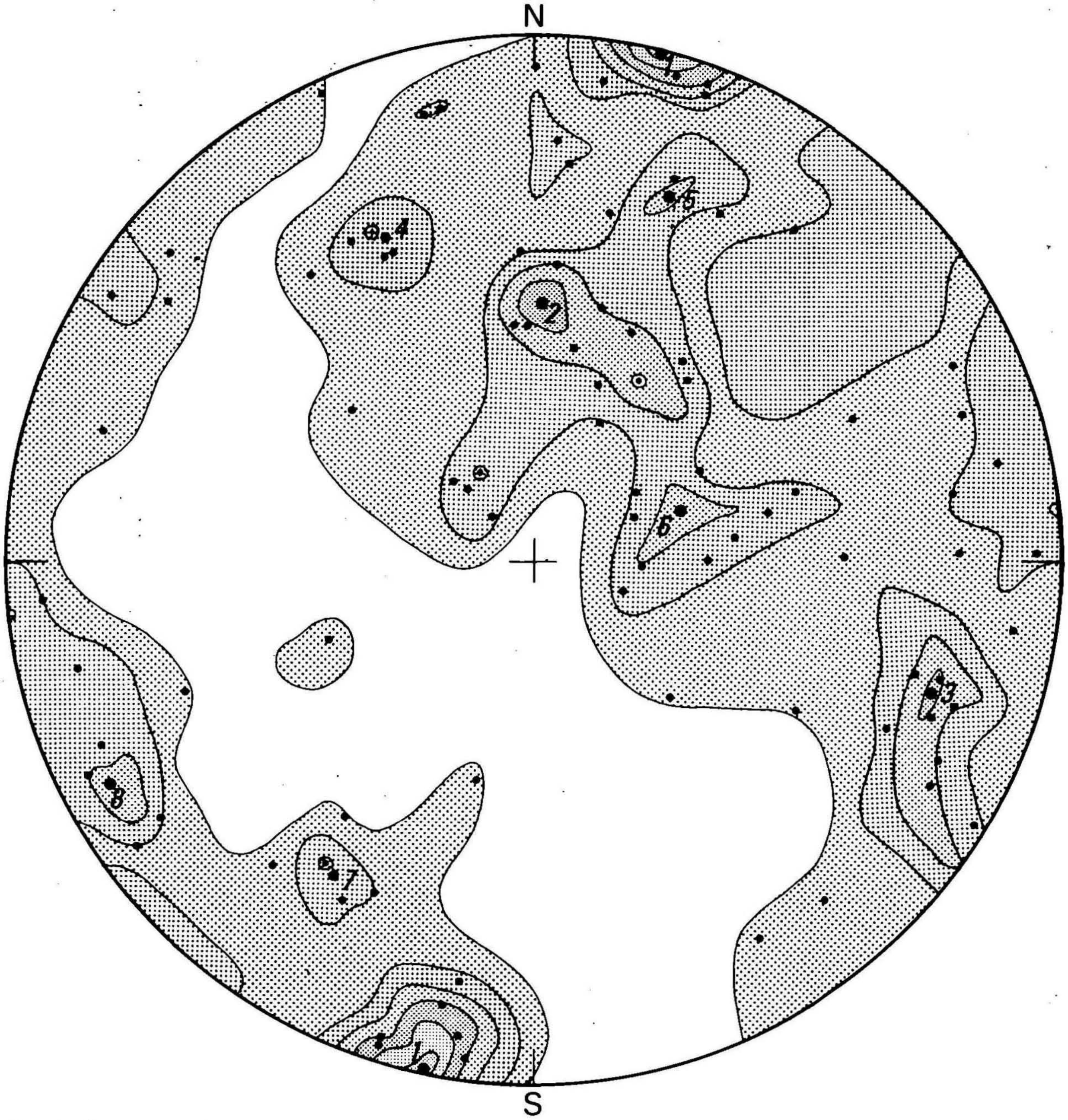
16/I55-16/65

Fig 7 Rose diagram showing preferential directions of joints




Record 1981/35 16/I55-16/66

Fig. 8. Histograms showing the variation in azimuth within main and secondary joint sets




Population percentage

| | |
|---|---|
| | 7·4 % |
| | 6·2 % |
| | 5·0 % |
| | 3·7 % |
| | 2·5 % |
| | 1·23 % |

Joint Sets

| Main | | Secondary | |
|---|---|---|---|
| • 1 | 106 – Vertical | • 4 | 064 – 60 S |
| • 2 | 090 – 40 S | • 5 | 110 – 65 S |
| • 3 | 022 – 70 W | • 6 | 163 – 20 W |
| | | • 7 | 125 – 60 N |
| | | • 8 | 151 – 80 E |

Record 1981/35 16/I55-16/45

Fig. 9 Stereogram of poles to joints from Tuggeranong Hill
*(Lambert. equal area net, lower hemishere projection)*

## JOINT SETS

| Main | | Secondary | |
|---|---|---|---|
| 1. | 106 - vertical | 4. | 064 - 60S |
| 2. | 090 - 40S | 5. | 110 - 65S |
| 3. | 022 - 70W | 6. | 163 - 20W |
| | | 7. | 125 - 60N |
| | | 8. | 151 - 80E |

The poles of the joint sets and of the various great circles that represent the planes of each pole were also plotted (Fig. 10). The intersection point of any two great circles represents a joint plane intersection. The line joining an intersection point to the centre of the net represents the direction in which a rock wedge formed by the two intersecting joints would tend to move; This direction is referred to as the plunge.

## GROUNDWATER

The groundwater levels in the southwestern pediment slopes at the foot of Tuggeranong Hill are usually within about 1 m of the base of drainage depressions. Patches of swamp vegetation indicate a high moisture content in the soils, and where such vegetation is also found on low rises that consitute the interfluves of the pediment, it reflects the poor drainage characteristics of the soils.

There is some evidence of groundwater seepage at the heads of gullies on the upper slopes of the hill. The soutwest-facing slope of the hill, the main target of this study, lies in shadow throughout most of the winter; soil moisture would remain relatively high, and the slope would be subject to regular frost freezing and thawing that would tend to open up joints and contribute to hillside creep. It is not uncommon for frost to remain on this slope throughout the day during winter. Whilst soil moisture and frost action could be regarded as contributary factors to instability for the purpose of this analysis they will be disregarded, and only considered as a variation of the strictly geometrical analysis of the stability of the slopes.

## SLOPE STABILITY ANALYSIS

Three types of instability are considered in the analysis of the joint systems in Tuggeranong Hill:

1. TOPPLING

High angle joints (such as sets 1, 7, and 8 - see Fig. 11) behind a slope separate blocks at the surface of the slope from the rest of the rock mass, and blocks may slide or roll out from the slope. Each block moves independently in reaction to the various forces, including gravity, that act on it, and movement out of such a face is called toppling. The conditions for toppling may be prepared by tree roots opening up joints, by frost-initiated expansion of water in joints as it freezes, or by the mechanical action of wedge-shaped blocks (Fig. 3).

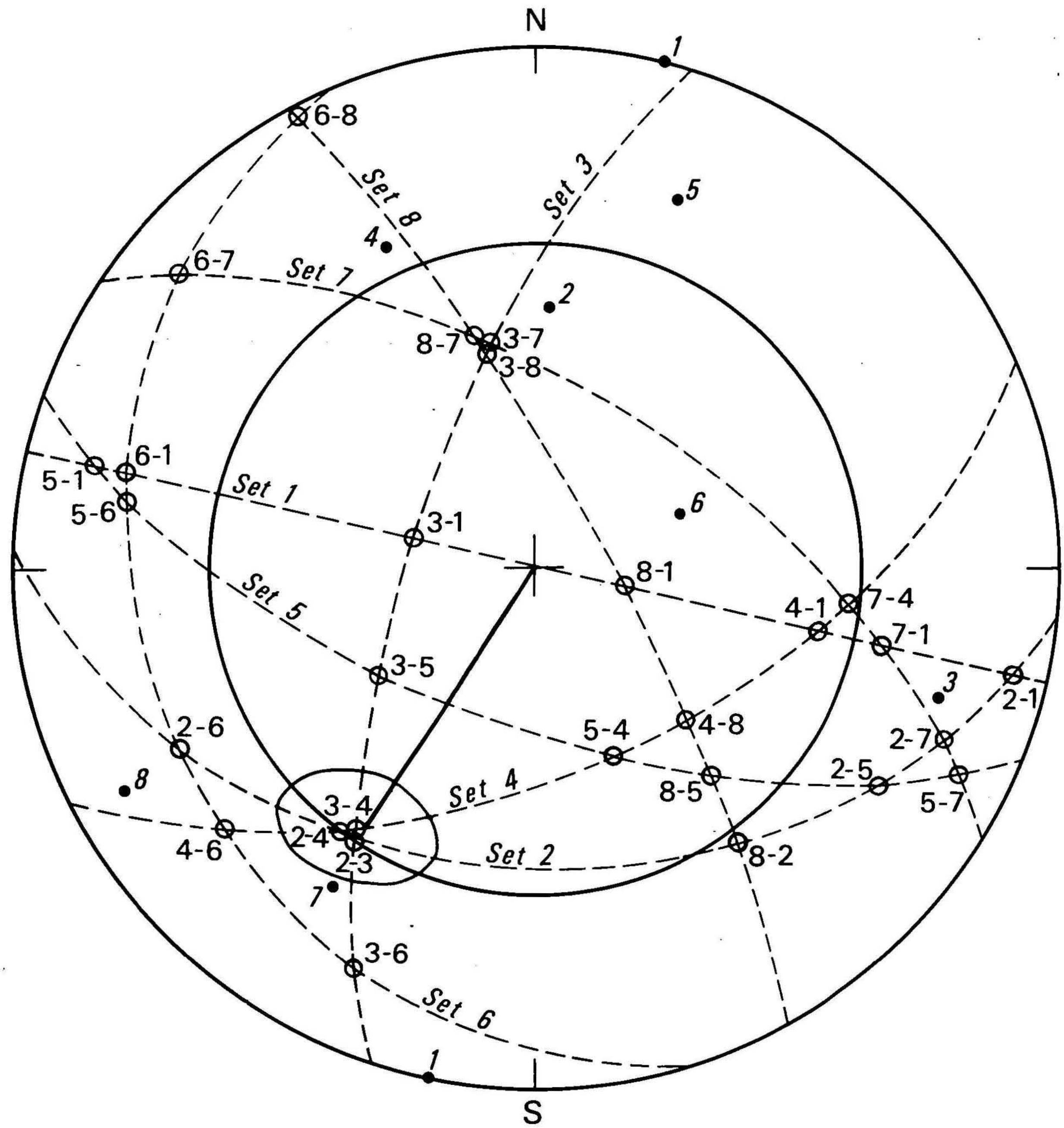
2. KINEMATIC INSTABILITY

Joints of set 6 (Fig. 11) are not as steep as the slope, and a block has freedom to move out of the face if it is pushed. Such movement would require a force (F) to be applied to the block, and would require the continued application of force to keep it in motion. If such a force ceased to act, the block would cease to move. Such a block is said to be kinematically unstable.

3. KINETIC INSTABILITY

Joints of set 2 (Fig. 11) are steeper than the angle of friction:* therefore, blocks on set 2 joints are held in position solely by the roughness and undulations of the joint surface. A slight change in conditions on the slope is all that is required to upset the equilibrium and, once the blocks are in motion, they will continue to move under the influence of gravity. Such blocks are said to be kinetically unstable,

* The angle of friction is the angle of an inclined plane on which a block, under the sole influence of gravity, is on the point of overcoming the friction between the base of the block and the inclined surface.

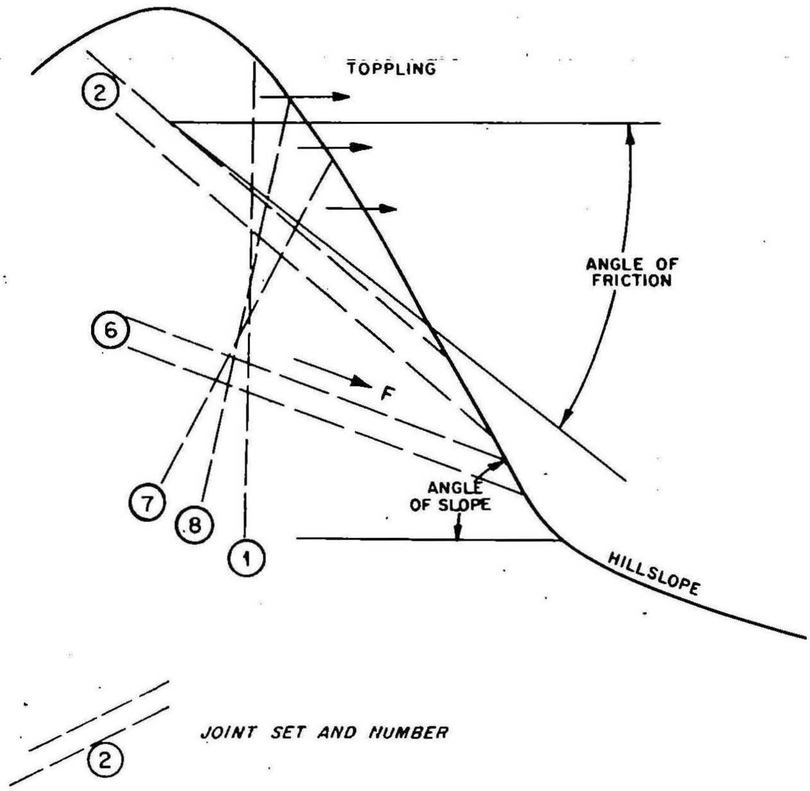



• 7 *Pole representing set 7 joints*

○ 2-3 *Plunge representing intersection of joints of sets 2 and 3*

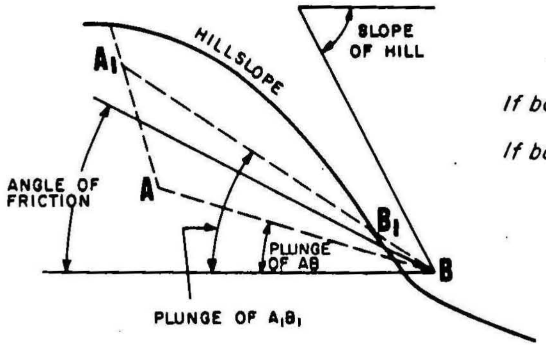
Record 1981/35 16/I55-16/48

Fig. 10 Stereogram showing poles and planes representing joint sets, and showing joint intersections




Record 1981/35 16/I55-16/68

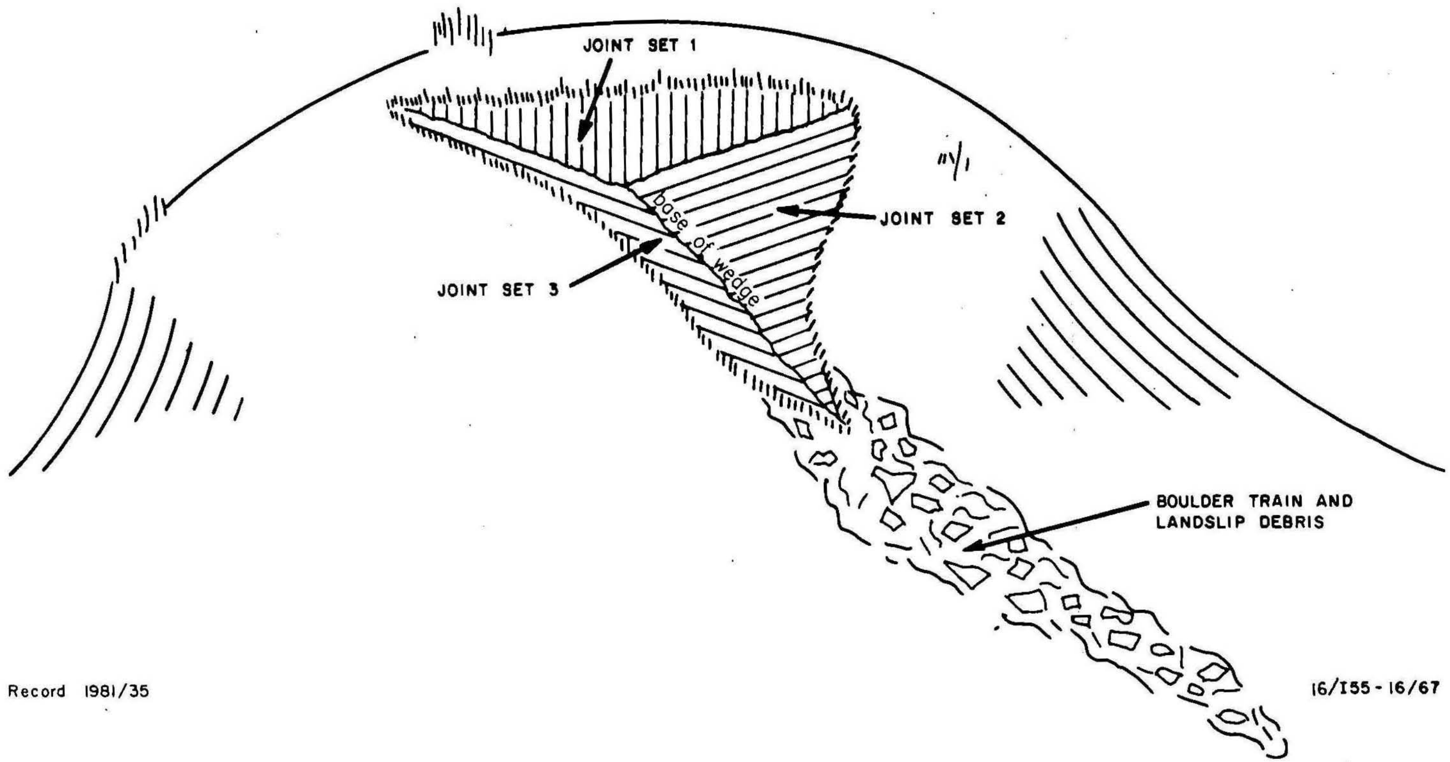
Fig II Diagram showing toppling and block movement on joints




*If base of wedge has slope A—B, the wedge is kinematically unstable;*

*If base of wedge has slope $A_1$—$B_1$, the wedge is kinetically unstable.*

## TUGGERANONG HILL




Record 1981/35

16/I55-16/67

Fig 12 Diagram showing joint orientation and criteria for wedge block failure.

Movement could be initiated by:

(i) an earthquake;

(ii) water lubrication of joints in times of exceptionally high rainfall; or

(iii) ice lubrication of joints with the advent of a colder climate with deeper frost penetration.

## WEDGE FAILURE

The terms 'kinematically unstable' and 'kinetically unstable' apply to wedges of rock formed by intersecting joints planes.

If the base of the wedge has a plunge that is less than the slope of the hill (as for AB in Fig. 12), the wedge is free to move out of the slope and is said to be kinematically unstable. However, if the plunge of the base of the wedge exceeds the angle of friction, (as for A,B, in Fig. 12) a condition of kinetic instability would exist, and the wedges would slide if the equilibrium was disturbed.

## APPLICATION TO TUGGERANONG HILL

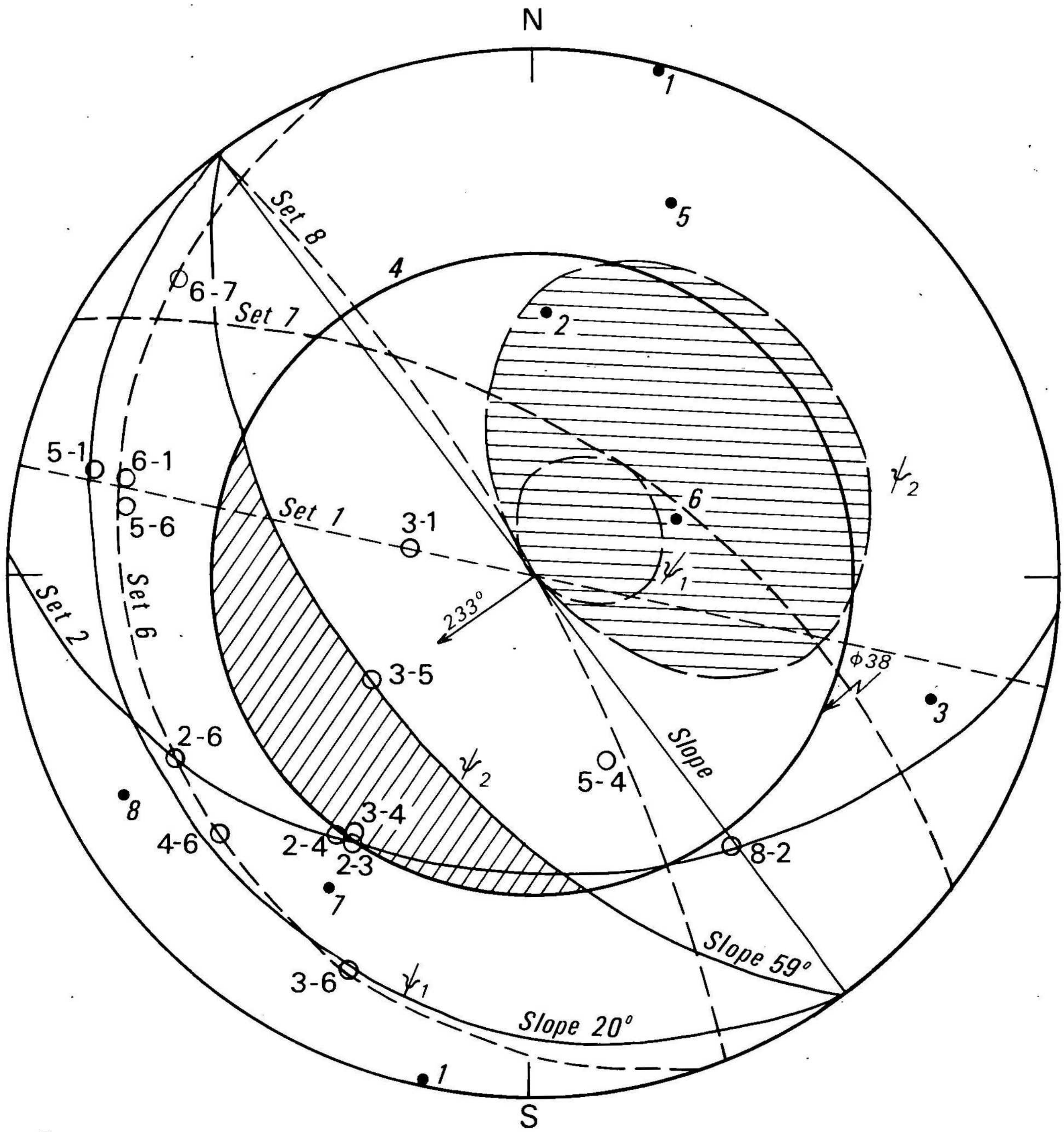
Four representative upper slopes on Tuggeranong Hill were selected for analysis (Plate 1). Slopes 1 and 2 lie within the zone from which earlier rockslides have taken place, while slopes 3 and 4 show no evidence of prior movement.

Slope 1 Slope bearing 233$^{o}$, angle decreasing from 59 to 22 degrees
Slope 2 Slope bearing 210$^{o}$, angle decreasing from a maximum that ranges from 54 to 59 degrees to a minimum of between 31 and 42 degrees
Slope 3 Slope bearing 275$^{o}$, angle decreasing from 53 to 43 degrees
Slope 4 Slope bearing 210$^{o}$, angle decreasing from 48 to 38 degrees

The stability of the slopes was analysed by three methods:

(i) a method outlined by McMahon (1971) that considers gravity and hydrostatic uplift as the only forces involved; failure may take place by block sliding on a joint surface, or be wedge sliding on two intersecting joints. If the surface on which the block or wedge rests, will intercept the slope ($\psi$), failure is kinematically possible;

(ii) a graphical method described by Hoek and Bray (1974), applied




• 5 Pole of joint set 5

○ 3-1 Plunge of wedge on intersection of set 3 and set 1 joints.

ψ 2 Elliptical area enclosing poles of planes with dip less than slope 2.

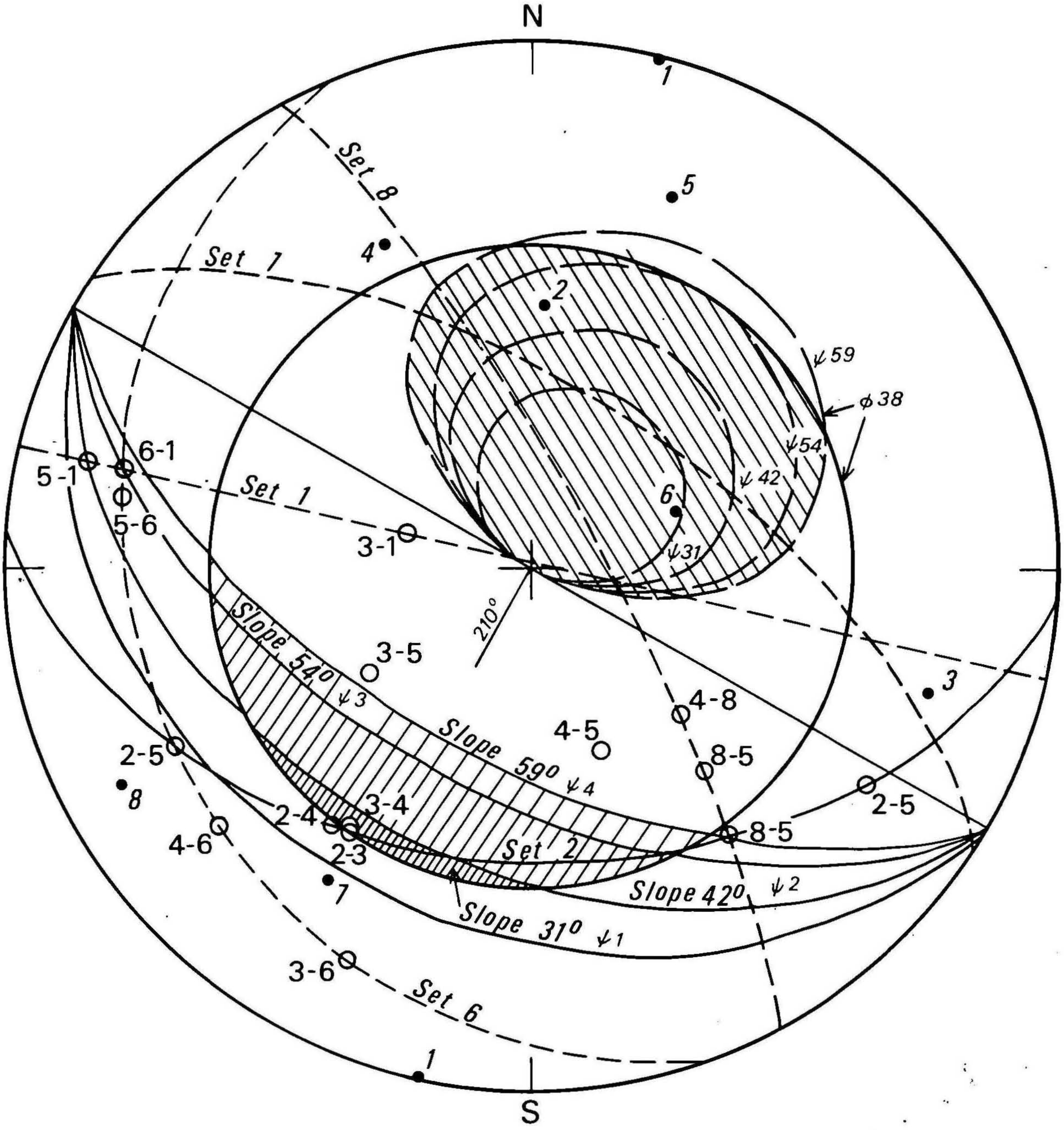
ϕ38 Small circle locus of poles of planes that dip at 38°, the angle of friction

(horizontal hatching) Polar areas defining planes of kinematic instability for various slope angles.

(diagonal hatching) Areas in which the plunge of joint intersections for defines a wedge block that is kinetically unstable

Record 1981/35 16/I55-16/49

Fig. 13 Stereogram — Slope 1, Bearing: 233°, Dip: 59–20°




• 5 *Pole of joint set 5*

○3-1 *Plunge of wedge on intersection of set 3 and set 1 joints*

ψ2 *Elliptical area enclosing poles of planes with dip less than slope 2*

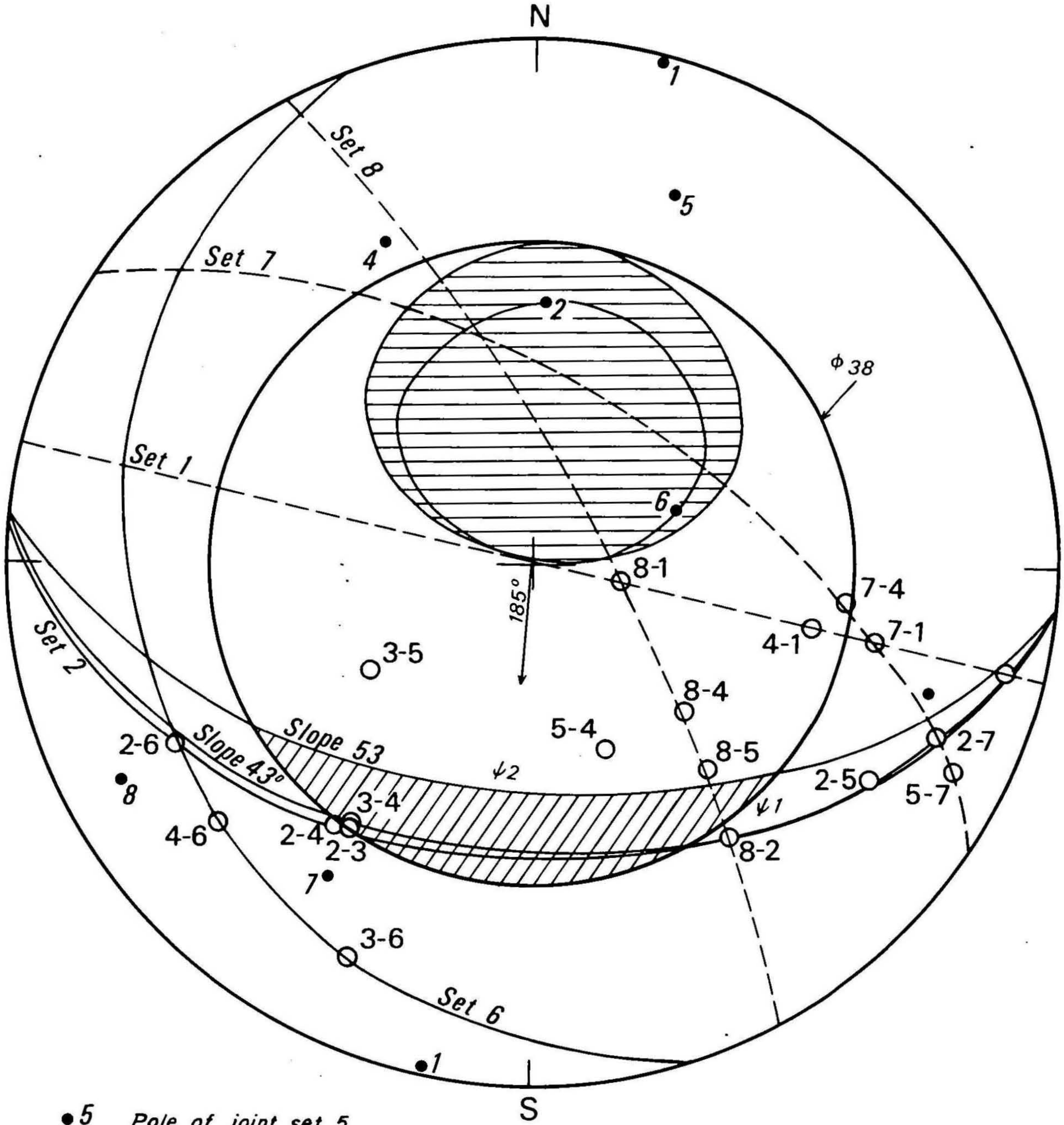
φ38 *Small circle locus of poles of planes that dip at 38°, the angle of friction*

\\\\\ *Polar areas defining planes of kinematic instability for various slope angles*

/// *Areas in which the plunge of joint intersections defines a wedge block that is kinetically unstable*



Fig. 14 Stereogram — Slope 2, Bearing: 210°, Dip: 31–59°




•5 Pole of joint set 5

○3-1 Plunge of wedge on intersection of set 3 and set 1 joints.

ψ 2 Elliptical area enclosing poles of planes with dip less than slope 2.

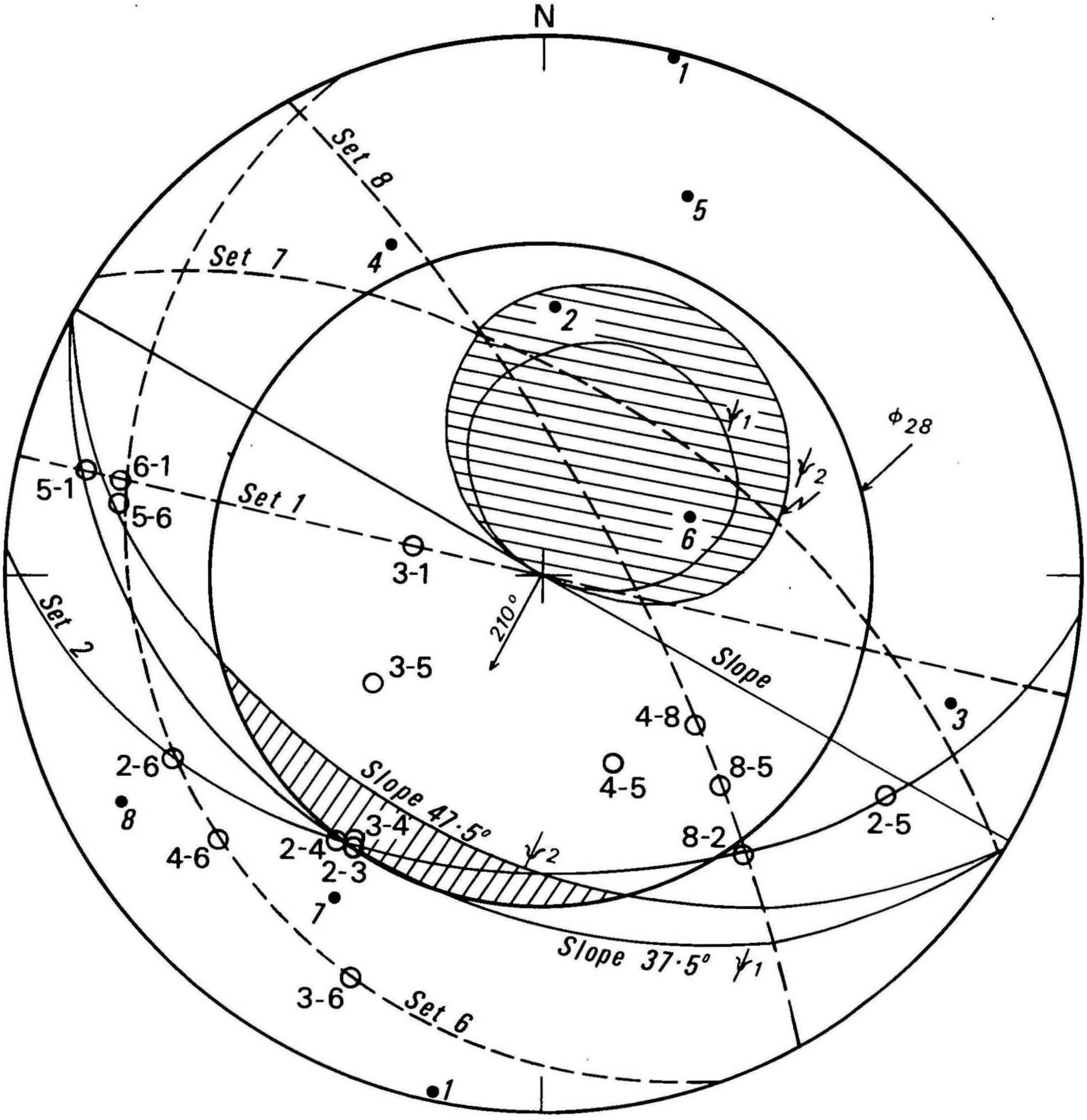
φ 38 Small circle locus of poles of planes that dip at 38°, the angle of friction.

Polar areas defining planes of kinematic instability for various slope angles.

Areas in which the plunge of joint intersections defines a wedge block that is kinetically unstable

Record 1981/35 16/155-16/51

Fig. 15 Stereogram—Slope 3, Bearing: 185°, Dip: 43-53°




•5 Pole of joint set 5

O3-1 Plunge of wedge on intersection of set 3 and set 1 joints

ψ2 Elliptical area enclosing poles of planes with dip less than slope 2

φ38 Small circle locus of poles of planes that dip at 38°, the angle of friction.

Polar areas defining planes of kinematic instability for various slope angles

Areas in which the plunge of joint intersections defines a wedge block that is kinetically unstable

Record 1981/35 16/I55-16/52

Fig. 16 Stereogram – Slope 4, Bearing: 210°, Dip: 37–47°

to failure by toppling; and

(iii) a method which infers an angle of friction (Ø) of 38 degrees, based on observations of blocks that showed partical movement along discontinutites, and then defines the areas of kinetic instability by stereographic analysis. Roughness and undulations of the surface were not taken into account in arriving at the angle of friction.

## SLOPE STEREOGRAMS

A stereogram was prepared for each slope on which the slope is represented by a great circle, and the joint set poles and joint intersections are also plotted (Fig. 13-16). A small concentric circle represents the poles of all planes that dip at 38 degrees, the angle of friction.

Steep joint sets (1, 7 and 8) whose poles are located on the downslope margin of all stereograms, represent joints that release blocks at the surface from horizontal restraint, and thereby contribute to toppling.

For each angle of slope (ψ), a small ellipse is constructed (the area of horizontal-line shading) so that the poles of all planes that dip at an angle less than the slope will lie within the ellipse eg. in figure 13, the poles of joint sets 6 and 2 lie within the larger ellipse, and would be kinematically unstable on a slope of 59 degrees ( $\psi$59).

The crescent-shaped area (with the diagonal-line shading) represents a zone in which the slope is greater than the angle of friction. Any joint plane passing through this area would be inclined so that slope ψ is greater than the dip of the joint plane and greater than the angle of friction (Ø). Blocks on such a plane (set 2 joints in Fig. 13 where slope is 59$^{o}$) would be kinetically unstable, and wedges defined by joint intersections that fall in this area would also be kinetically unstable (wedges 2-3, 2-4, and 3-4 in Fig. 13).

The result of the slope analysis has been summarised in Table 1.

TABLE 1

SLOPE STABILITY SUMMARY

STRUCTURAL ELEMENTS AFFECTED

As the slope angle increases, additional elements of structure are affected; the elements listed in each column are additional to the unstable units in the proceding columns.

| | $<20^\circ$ | $20 - 37^\circ$ $(20 - 32^\circ)$* | $38 - 42^\circ$ $(32 - 37^\circ)$* | $42 - 58^\circ$ $(37 - 53^\circ)$* | $>58^\circ$ $>(53^\circ)$* |
|---|---|---|---|---|---|
| KINETIC INSTABILITY | – | – | wedges 2 - 3, 2 - 4, and 4 - 3 | blocks on set 2 | wedge 3 - 5 followed by 4 - 5 |
| KINEMATIC INSTABILITY | - | blocks on set 6; wedges 2 - 6 3 - 6, 4 - 6 5 - 6 consecutively | minor additional wedge elements depending on slope bearing. | | |
| TOPPLING | All blocks associated with joint sets 1, 7, and 8 and various wedge combinations with those sets according to slope bearing. | | | | |

* Slope angles in brackets are those that would apply if an arbitary reduction in the angle of friction of 5 degrees was postulated.

The discussion of stability has been simplified by assuming that the pole of a set represents joints with a single orientation, whereas it is clear from Figures 8 and 9 that there is a scatter of joint poles within each set. As each joint has the potential for movement, it is more realistic to consider a small circle as a locus of the intersection points for two sets of joints; the circle would project on to the stereogram as an ellipse (Fig. 10).

Another factor that needs to be considered in evaluating slope stability is the effect of groundwater on the angle of friction, particularly after rainfall.

The effect of these variables can be approximated by reducing the angle of friction. An arbitrary reduction in the angle of friction by 5 degrees would amend the slope values at the top of Table 1 to those shown in brackets. It should be remembered that the stereogram analysis is an approximation, to assess the condition of stability. It cannot predict failure; it can only indicate stability or instability. The relationship between instability and failure is governed by variables other than joint orientation, such as the existence of clays in joints, moisture content of clays, weight of overburden, and dynamic forces such as earthquakes.

## RELEVANCE TO URBAN DEVELOPMENT

The following aspects of development in this area require consideration.

1. Do the unstable blocks constitute a hazard to personal safety?
2. What is the magnitude of the risk to life and property if development proceeds on the footslope below the kinetically-unstable upper slopes of Tuggeranong Hill?
3. Does the landslip material overlying the Tuggeranong Clay provide undue difficulty for the installation of services, or for the founding of buildings?

### 1. Unstable blocks

The unstable blocks will at some time move downslope; when this event might take place cannot be predicted, although it will probably be when the slopes are saturated or frost-affected. There is no practical means of stabilising boulders on the slope that would not further damage the stability of the hillside, although some blocks could be barred down, possibly to rest on a gentler slope. The boulders constitute a risk to personal safety; however, their movement might be delayed by promoting the growth of trees on the upper slopes, and the establishment of large trees on the footslopes to provide some brake on blocks that roll downslope.

### 2. Rockslide risk

The risk of a rockslide is ever present on a kinetically unstable slope, and on failure, a slide could be expected to advance across most of the footslope at catastrophic speed. Whilst the installation of drainage holes in the hill would be expected to improve some aspects of stability in the hillslope, it would not alter the basic condition of unfavourably oriented joints, and the risk to life and property would remain. A major engineering project, such as the removal of the top of the hill, would be required to remove the risk of rocksliding. Such a project would further increase the cost of urban development in the area.

3. Installation of services

Boulders could be a nuisance during the excavation of trenches on the footslope; the penalty is likely to be an increase in the cost of development. Some differential settling could also occur by boulders in the material on which structures are founded.

## CONCLUSIONS

1. The lines of boulders, some of which range to 3 m across, on the footslopes southwest of Tuggeranong Hill were deposited by rockslides that originated on the upper slopes of the hill, and transported rock debris up to 600 m across the footslopes. the events took place in post-glacial times, but then climate at that time is not known.
2. The southwestern face of Tuggeranong Hill has slopes ranging to 59 degrees, and displays a number of joint planes so oriented as to promote the toppling of blocks; many large blocks on the slope are unstable, and constitute a hazard to personal safety.
3. The barring-down of blocks to rest on a lesser more-stable slope could effect some temporary improvement; however, in the longer term, the growth of large trees on the slopes of the hill and on the footslope could be expected to retard the progress of toppled blocks, and reduce the damage they might cause.
4. Wedge blocks 2 - 3, 2 - 4, and 3 - 4 are kinetically unstable on slopes greater than 33 degrees; additional wedge blocks 3 - 5 and 4 - 5 are also unstable where slopes exceed 53 degrees.
5. Blocks resting on joints of set 2 are kinetically unstable on slopes greater than 42 degrees.
6. Kinetically-unstable wedge blocks and block instability on joint planes are the slope conditions required to initiate a rockslide, and constitute a risk to life and property on the footslopes. Such a rockslide would sweep across the footslopes for hundreds of metres at great speed.
7. There is no simple method of stabilising joints and wedge

blocks that are kinetically unstable. Drainage may be improved so that equilibrium is less readily disturbed, but instability will remain. Removal of the top of the hill does not appear to be a viable option.

8. Whilst the thickness of rock debris overlying the Tuggeranong Clay was only 45 cm in the observation pit, a reliable estimate of the thickness of rock debris could not be made without a substanital augering programme; these boulder deposits may provide some problems of differential settlement in foundations, but would not constitute a major obstacle to development.

## RECOMMENDATIONS

1. Consideration should be given to the barring down of blocks that are in imminent danger of toppling.
2. Regeneration of tree growth (particularly large trees) on the hillslopes and footslopes shoud be undertaken as a means of restricting the damage arising from toppling rock or rockslides.
3. Access to the hillslopes shoud be discouraged, to reduce the risk of rocks being deliberately or inadvertently dislodged from steep slopes.
4. Urban development on the footslopes below Tuggeranong Hill should be undertaken without considering the costs that might be incurred in stabilising the hillslope, and servicing blocks in materials containing numerous boulders.

## REFERENCES

HOEK, E., & BRAY, J., 1974 - Rock slope engineering. The Institute of Mining and Metallurgy, London.

JACOBSON, G., KELLETT, J.R., LAWS, A.T., SALTET, J.A., & VANDEN BROEK, P.H., 1975, - Urban geology of Tuggeranong, A.C.T. Bureau of Mineral Resources, Australia, Record 1975/93 (unpublished).

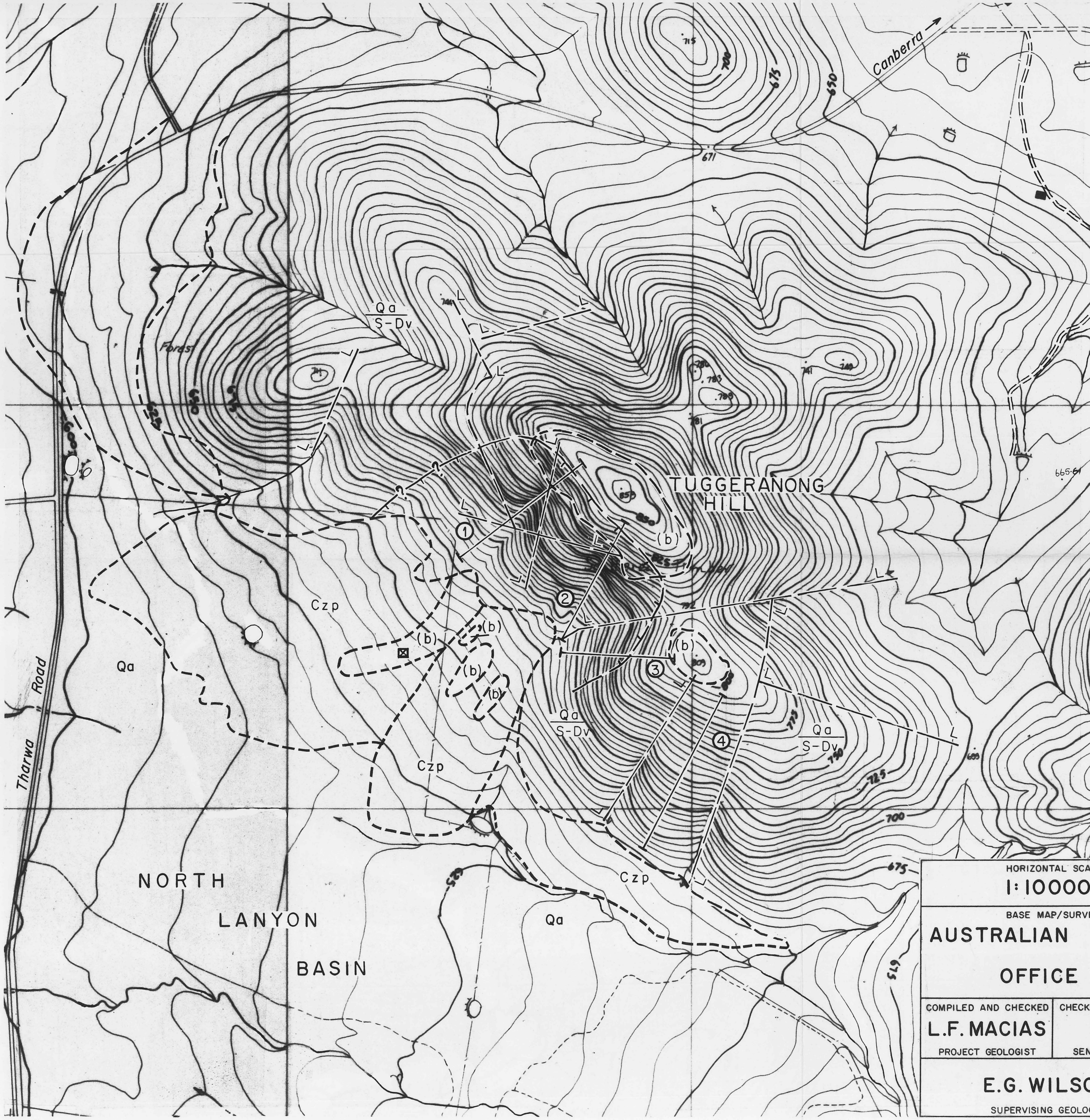
JACOBSON, G., VANDEN BROEK, P.H., & KELLETT, J.R., 1976 - Enviromental geology for urban development - Tuggeranong, Australian Capital Territory. BMR Journal of Australian Geology & Geophysics, 175-192.

KELLETT, J.R., in prep. - Hydrogeological investigations at two basins at Lanyon, Australian Capital Territory, 1974-76. Bureau of Mineral Resources, Australia, Record.

McMAHON, B.K., 1971 - A statistical method for the design of rock slopes. Proceedings of the First Australia-New Zealand Conference on Geomechanics, Melbourne, Vol. 1, 314-321.

MENDUM, J.R., 1975 - Geological investigation of Tuggeranong damsites Murrumbidgee River, A.C.T., 1968. Bureau of Mineral Recources Australia, Record 1975/38 (unpublished).

VAN DIJK, D.C., 1959 - Soil features in relation to erosional history in the vicinity of Canberra. CSIRO Australian Soil Publication 13.




| | |
|---|---|
| Qa | *Skeletal soil on upper slopes (b)-with boulders* |
| Czp (b) | *Colluvium rock rubble and boulders on foot slopes (b)-numerous boulders* |
| S-Dv | *Blue-grey and purple porphyritic rhyodacite (b)-boulders* |
| - - - - - | *Geological boundary* |
| L — L | *Lineament* |
| | *Landslip scar* |
| ④ | *Slope 4* |
| | *Farm dam and drainage* |
| ⊠ | *Observation pit* |
| ·783 | *Spot elevation* |
| —700— | *Contours in metres (interval-5 metres)* |

| | |
|---|---|
| HORIZONTAL SCALE<br>1:10000 | COMMONWEALTH OF AUSTRALIA<br>**BUREAU OF MINERAL RESOURCES**<br>CANBERRA, ACT |
| BASE MAP/SURVEY<br>AUSTRALIAN SURVEY OFFICE | TITLE<br>GEOLOGY OF TUGGERANONG HILL |
| COMPILED AND CHECKED: L.F. MACIAS, PROJECT GEOLOGIST; CHECKED AND APPROVED: SENIOR GEOLOGIST | PROJECT<br>SLOPE STABILITY: TUGGERANONG HILL |
| E.G. WILSON<br>SUPERVISING GEOLOGIST | TO ACCOMPANY Record: 1981/35; DRAWN BY; DRAWING NUMBER I55/A16/2003 |