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1976/31. Engineering geology and slope stability analyses of the Round Hill quarries, Burnie.

W.R. Moore

The Senior Mining Engineer, Department of Mines, Burnie requested that the Engineering Geology Section 'establish guide lines that were to be the basis of the final design for the working and rehabilitation of the Round Hill area'.

This brief implies that quarrying could continue at Round Hill and if planned and on a sufficient scale could economically produce suitable aggregate as well as meeting the environmental and safety requirements of the Department of Environment, Department of Mines and the Burnie Council. Three major geological questions would have to be answered to meet the above requirement.

(1) Would the geological structure influence future quarrying operations and the stability of the quarry face at Round Hill?
(2) What would be the steepest stable face possible for such a quarry?
(3) What would be the maximum bench height and width for such a quarry?

This report is based on one day of general site inspection of the various quarries and outcrops on Round Hill, four days of structural measurements and photography and one day of refraction seismic firing. The location of the slope stability structural analyses lines, and seismic lines are shown on Figure 1.

GEOLOGY

Quartzite and slate (Precambrian)

The sedimentary rocks of Round Hill are mapped as belonging to the Burnie formation of Precambrian age and are composed of quartzite and slate, (Gee and Gulline, in press). The sub-greywacke rocks are complexly and closely folded into a series of thick quartzites alternating with thin slate or slatey mudstone. The quartzites are of silt and sand grade in beds which are frequently over one metre in thickness. The slates usually form the subordinate beds and average 100 mm in thickness. Only in Section 6 was slate dominant and in this section it was soft enough to be described as a cleaved mudstone.

The quartzite is well bedded and strongly jointed; it has a minimum of two sets of joints which are normally steeply dipping. Three sets of discontinuities therefore occur in most of the structural sections measured. Some areas of overturned sediments occur on the shore platform but not in any of the measured sections on Round Hill. Minor sedimentary structures such as laminar bedding, graded bedding, flute casts and load casts are common in the quartzite and the slate shows well developed sets of cleavages.

In addition to the bedding and joints a set of near-vertical NE-SW faults pass through the Round Hill area. All of these major discontinuities can be clearly seen on the rock platform along the shoreline at Round Hill and are well illustrated on aerial photographs.

Talus deposits (Pleistocene?)

The talus forms an important quarrying material at Round Hill. Although

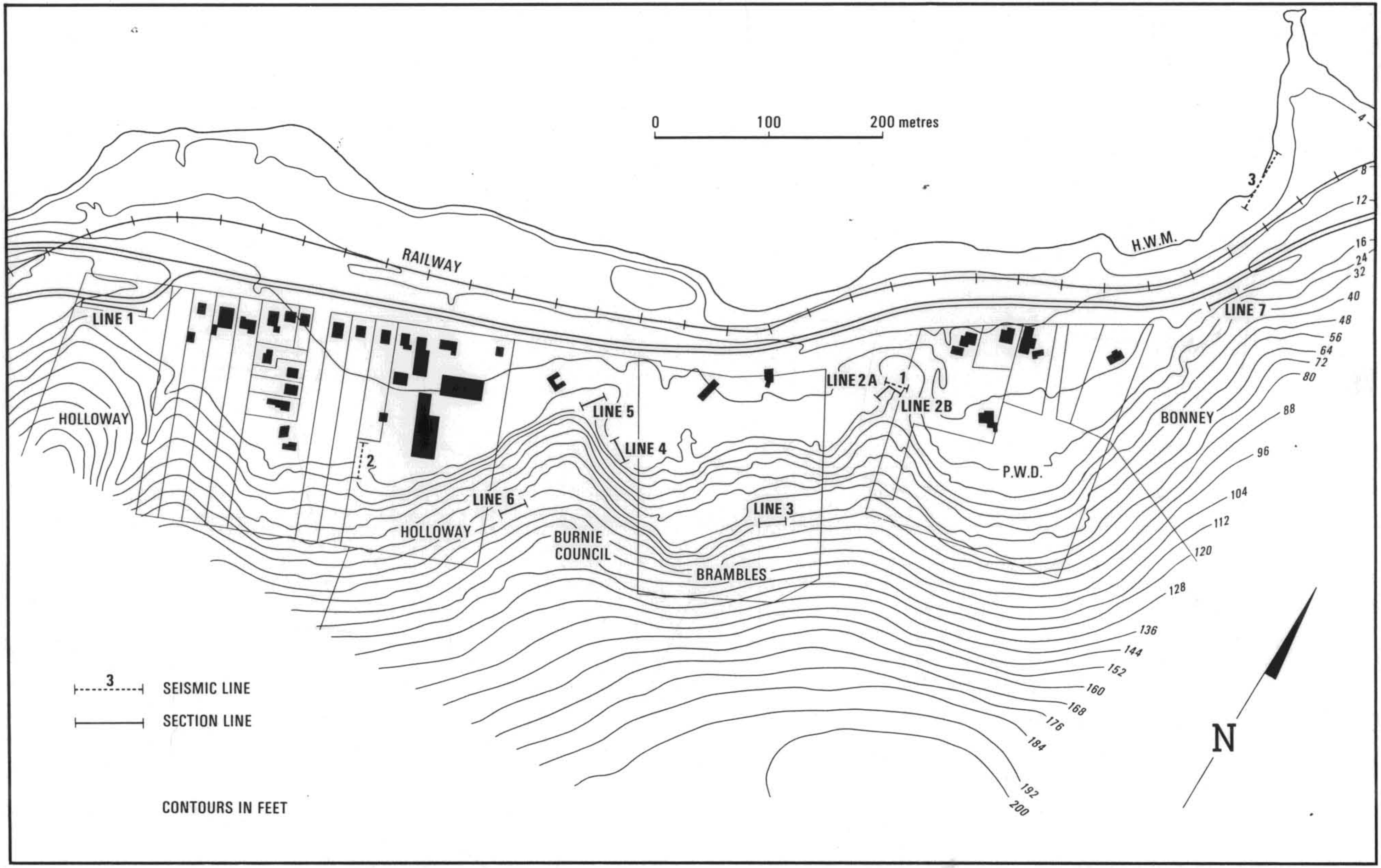

Figure 1. *Location of quarries, seismic lines, and structural analysis lines*

5 cm

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most of these deposits have now been worked out by past quarrying, outcrops showing the original thickness of this material at the base of Round Hill have been preserved between the boundaries of some of the quarry leases (plate 1). The talus is probably a solifluction deposit of Pleistocene age.

The material is a very poorly sorted gravel containing quartzite fragments, ranging in size from small pebbles to large blocks. The talus appears to have been deposited over an irregular rock surface. Although the matrix is probably rock flour it becomes cemented (plate 2).

The deposits are surprisingly thick on Round Hill and extend high up the slope and thick deposits are visible at the top of the Public Works Department quarry about 60 m above sea level (plate 3). The talus deposits thin rapidly above this level as seen on the highest bench at Holloway's quarry and a change in slope visible 10-15 m above this bench may mark the limit of the deposit.

Beneath the talus deposit is a soft weathered zone of the quartzite and mudstone. The talus and upper part of the weathered zone comprise most of the superficial material that has so far been quarried (plate 4).

The angle of repose of these talus deposits is remarkably high and even though slumping does occur (plate 3), the angle of repose is still high (45°). The high angle of repose is due to the cementing properties of the matrix material that enables the talus deposit to adhere to the underlying rock as in the gunite technique used by civil engineering contractors in tunnels and road cuttings.

The talus has a much higher angle of repose than that in Holloway and Brambles stockpiles of aggregate which range between 30 and 35°. Even when the talus is pushed over from the high benches at Holloway's pit and rests against the pit face, the talus rests at 35-37°. The cementing property of the talus matrix is illustrated where it has been washed down and cements itself to the walls of the open joints in the rocks below.

No attempt has been made to estimate the thickness of the talus remaining on the higher slopes of Round Hill either by mapping or by geophysical work. From the exposures in the quarries it is evident that the amount of talus deposits remaining on the lower slopes is insignificant compared with the amount that has been quarried over the past 70 years so that a change from the quarrying of the superficial deposits to the quarrying of the underlying rock must occur in the near future. The operators past methods of quarrying and their operational costs will have little relevance to future quarrying operations. Up to the present time very little blasting has been undertaken on Round Hill, and most of the quarrying has been by bulldozing the superficial deposits. Some ripping by heavy machinery may have occurred but it is impossible to evaluate how much.

GEOPHYSICAL WORK

Refraction seismic methods were used to indicate if the rock to be quarried in the future would require the use of explosives or would be rippable by heavy machinery. Spread 1 was fired where the talus and some of the weathered zone had been removed. Spread 2 was fired over one of the remaining pockets of talus where no bedrock was exposed. Spread 3 was fired on the shore rock platform where the weathered zone had been removed by wave action.

The talus has a low seismic velocity (610-910 m/s) and consequently this material can be removed by bulldozing with little or no ripping. The velocity in the weathered quartzite and slate ranges from 1300-1700 m/s, and even at the upper end of the velocity scale would still be rippable by heavy machinery. The unweathered quartzite and slate have seismic velocities of 3000-3600 m/s (as high as 4500 m/s on the rock platform). This material cannot be ripped and will require the use of explosives.

In both spreads fired in the quarry the weathered zone is thin (1.5-2.5 m).

The seismic velocities show that when the superficial deposits have been worked out and the underlying rock is being quarried, pre-splitting techniques using explosives will be required. To reduce the costs using these techniques the quarry face should be designed to take advantage of the major discontinuity in the rock which in the quartzite and slate is the bedding.

Unfortunately most of the existing quarry faces on Round Hill are in an E-W direction with the bedding dipping steeply into the face. With this face configuration large amounts of explosive will be required to lift the face forward to avoid secondary blasting and slope stability problems are likely to occur.

SLOPE STABILITY ANALYSIS

Seven lines were measured on most of the available continuous exposures of about 30 m in length between Bonney's lease in the east and Burnie Council lease in the west. It should be emphasised that the following analyses concern the rock and not the talus.

The angle of friction for these analyses has been assumed to be constant and a conservative figure of 30° has been adopted. No shear test was undertaken on a sample of this rock. Back analysis from two wedge fractures that could be measured indicates that the assumed angle of friction is a close approximation. Also the joints and bedding faces in the quartzites are smooth and a figure of greater than 35° for the angle of friction would appear unrealistic.

Line 1

This line (plate 5) was measured along a bench 8 m above the roadway at the eastern end of Round Hill in the Burnie Council lease area. The bedding plane (A) is the dominant discontinuity. Plane B is a well developed sub-continuous joint. The stereo-plot indicates a strong potential for wedge failure with a plane of inclination of the intersection of the two discontinuities surfacing on the slope face of the bench. This bench face has a dip of 62° at 358°. The direction of sliding of these potential wedge failures is 34° at 361°.

Two wedge failures are present on this bench and when plotted fall into the zone of instability between the friction circle for the assumed friction angle and the slope of the bench face. Wedge 1 slid in a direction of 356° with an angle of inclination for the intersection of the two faces of the wedge at 40°. Wedge 2 slid in a direction of 349° and angle of inclination of 43°. To stop these wedge failures the angle of friction would have to be increased to 40-43° or the face angle would have to be lowered to 30°.

From the stero-plot if the quarry face was striking in a N-S direction with a component of dip to the west, planar failure would occur even if the slope of this face was as low as 30°. Such a planar failure has occurred on a low angle face immediately south of Line 1 as shown in Plate 6.

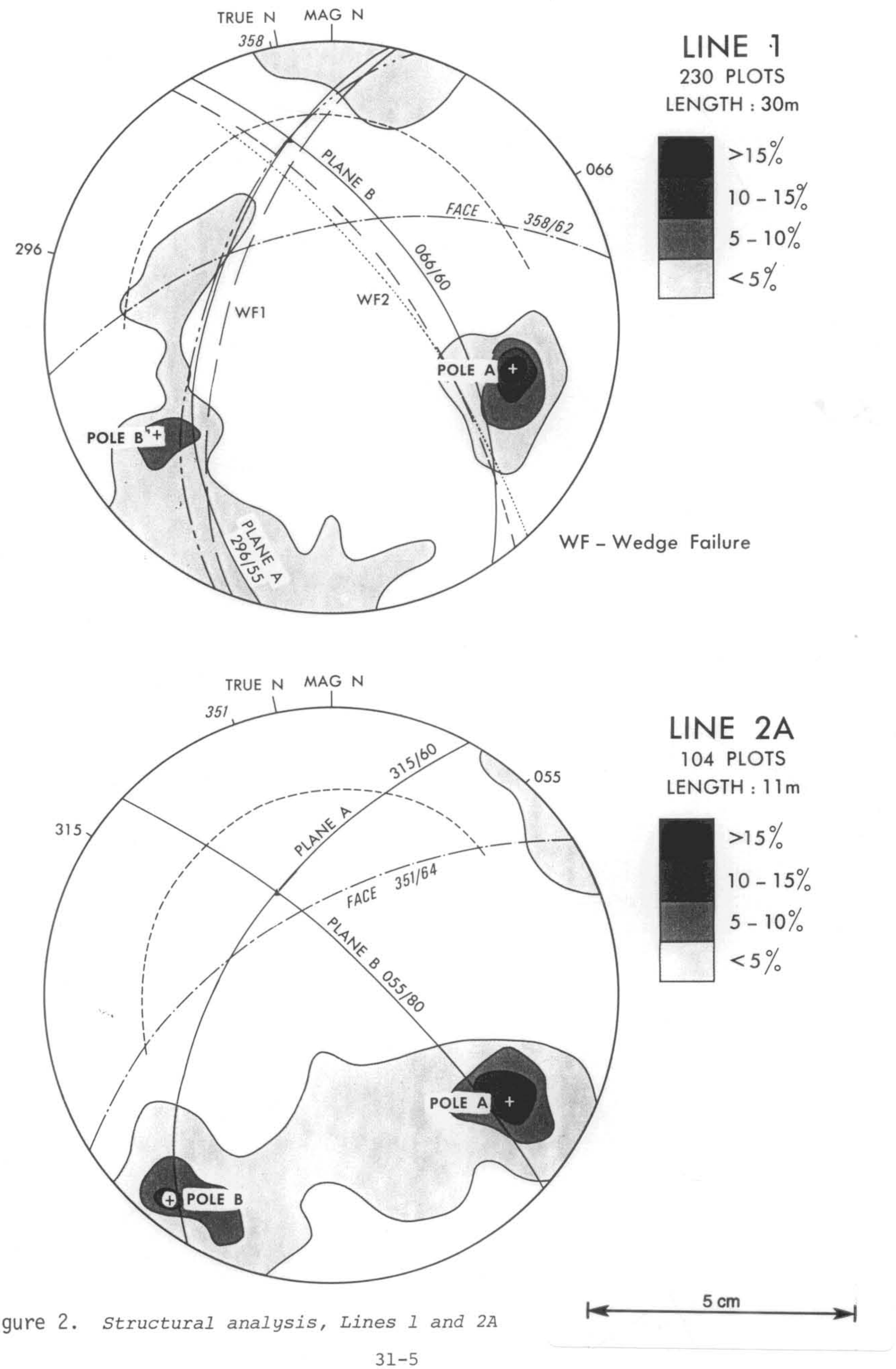


Figure 2. *Structural analysis, Lines 1 and 2A*

Line 2

This line was measured as one continuous section behind the Red Knoll. The alignment of the quarry face changes 10 m from the eastern end of the section, consequently the two sections are plotted separately.

Line 2a. Two major discontinuities are present on Line 2a (plate 7) both of which are joints. Set B is a set of joints influenced by two parallel faults that are exposed close to the western end of this section. These faults have a dip of 70 and 75° at 046°.

The bedding plane (45° at 161°) is not shown on the plot as most of the section is measured along the strike of the bedding. As the bedding dips towards the face it is not important for the assessment of slope stability.

The intersection of the two sets of discontinuities falls within the zone of instability between the friction angle circle and the great circle for the quarry face. Wedge fractures can be anticipated which will slide in a NW direction on a bearing of 351° with an average angle of inclination for the intersection of the two sets of discontinuities of 55°, but which can be as low as 35°.

Because of the scatter of the poles of Sets A and B planar failure may equally occur.

Both wedge and plane failures can be seen above the line measured.

Line 2b. In this section (plate 8) two sets of discontinuities are found. Set A is sub-continuous set of joints and Set B is the bedding which because of the swing in quarry face direction appears as a concentration on the plots.

A nose of a small fold exposed opposite the section forms Red Knoll and causes the bedding to swing giving it a scatter between B_1 and B_2.

Wedge failure is not likely to occur because the angle of inclination of the intersection of the two sets of discontinuities is steeper than the quarry face angle the wedge will not surface on this face, although the scatter of 20° in this plot indicates that this type of slope failure is possible.

Because of a concentration of plots of Set A discontinuities planar slope failures are considered more likely. Such failures are visible above this section line (plate 8).

Line 3

The stereo-plots show two major sets of discontinuities both of which are steep dipping sub-continuous joints (plate 9). The bedding dips 50° at 109° and appears as a wide zone of 2-5% concentration of poles in the NW quadrant of the plot. As the bedding dips into the face it does not contribute to slope instability.

Wide wedge failures are possible due to the intersection of the two sets of joints in the zone of instability between the friction angle circle and the great circle for the face. These wedge failures can be anticipated to slide on 289° bearing with steeply inclined plane of intersection of 48°. If the face slope was lowered to 35° the danger of wedge failure would be alleviated (assuming that the present direction of dip was maintained). Planar failure from the Set B joints is considered more likely. Some small scale planar failures do occur.

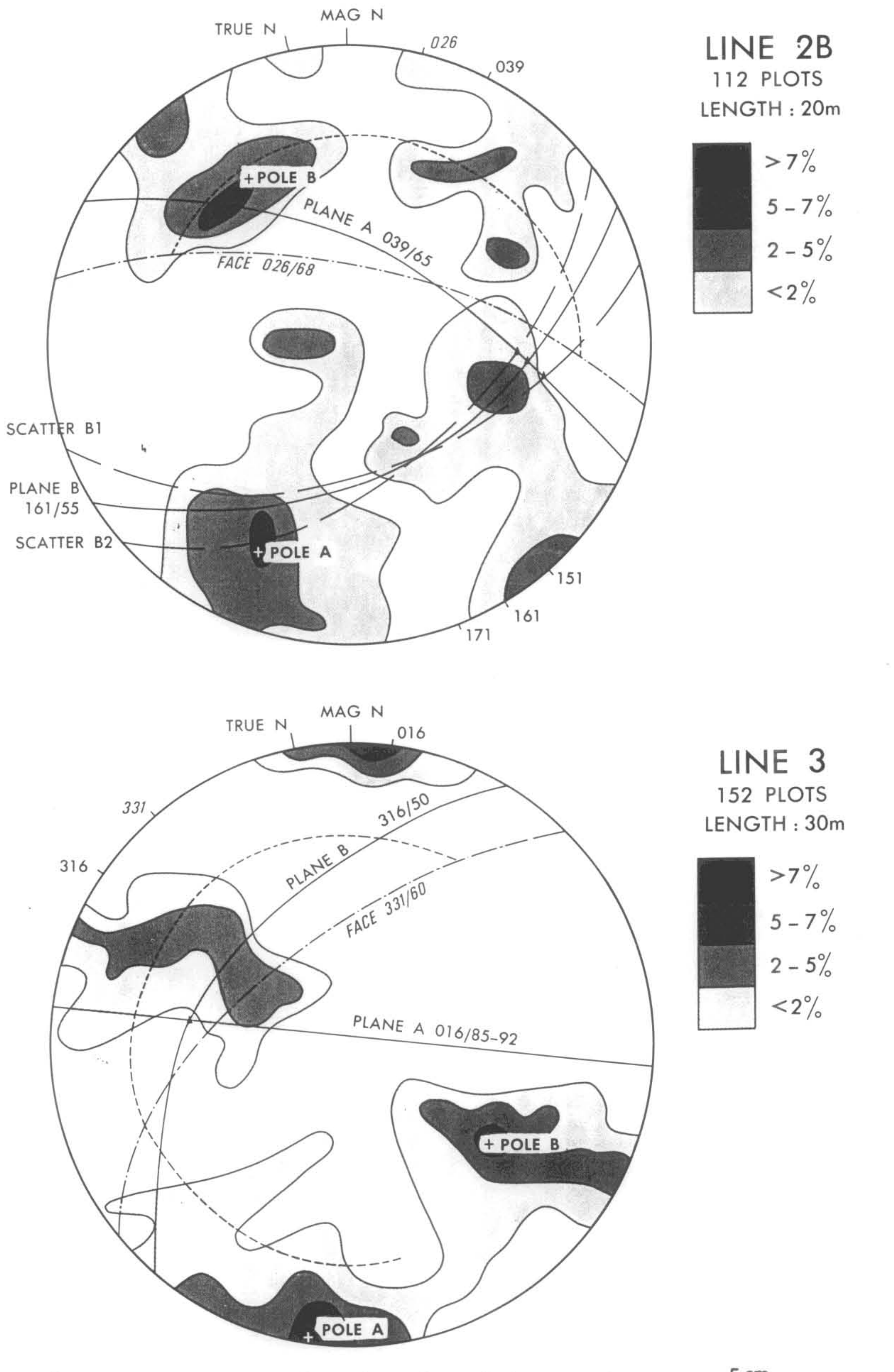


Figure 3. *Structural analysis, Lines 2B and 3*

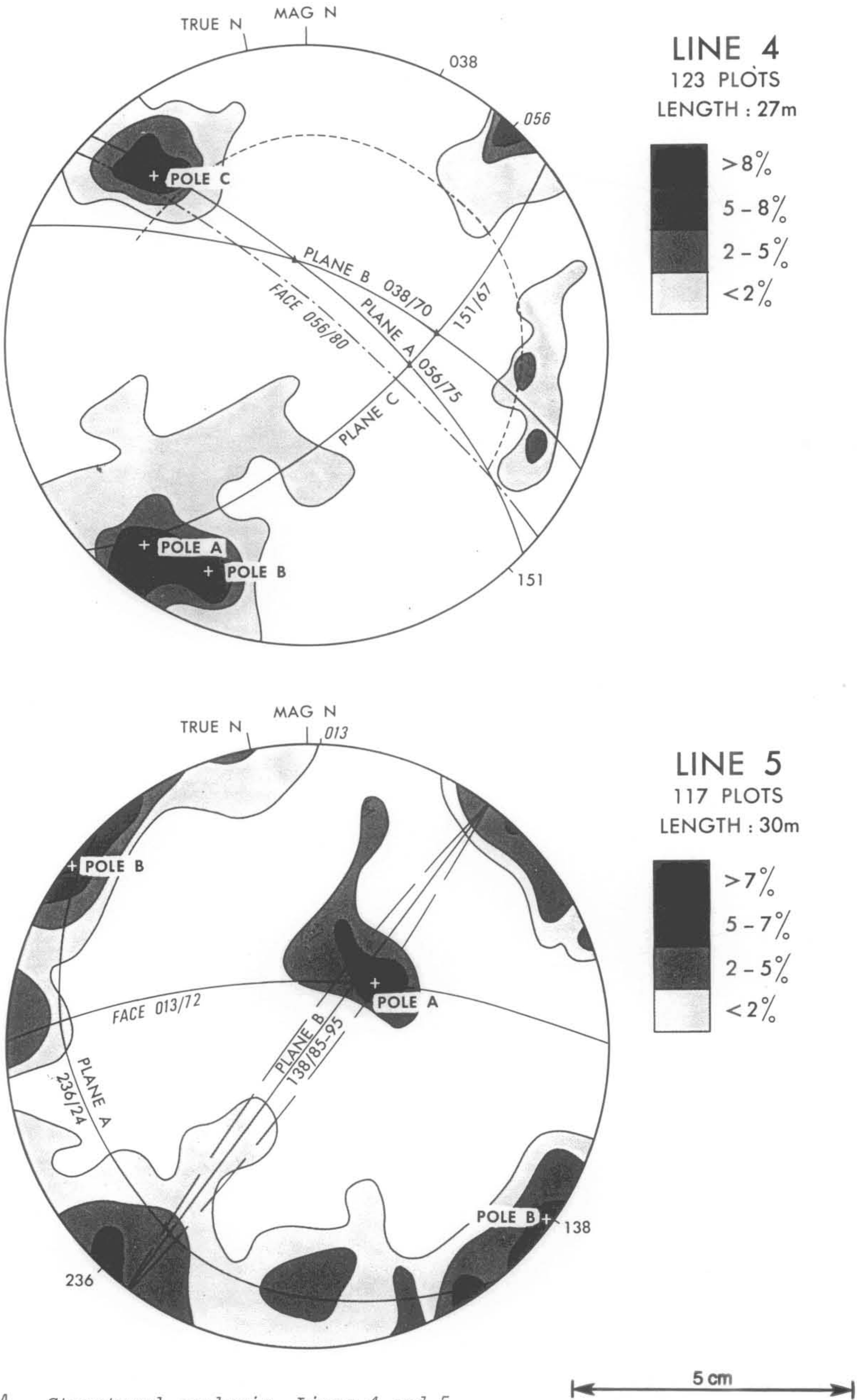


Figure 4. *Structural analysis, Lines 4 and 5*

Line 4

The stereo-plot of this line shows three sets of discontinuities. Set A and B are a well developed steep set of joints and Set C is the bedding (plate 10). The section is at the base of the SW limb of a fold exposed in the 20 m face of Holloway's pit which slopes at 80° (plate 11). The fold is cut off at the south-western end of the pit by a fault; the fault plane dips 85° at 336°. This fault separates the stable fold area of the pit from the unstable area (line 5) above the crusher.

The bedding is the major discontinuity as the joints are very tight. This is probably the only locality where explosives have been used extensively to trim a face on Round Hill.

Small wedge failures are possible due to the intersection of the two sets of discontinuities A and B, and A and C, but the angle of inclination of these intersecting planes is very steep, 66 and 63°. The intersection of joint Set B and bedding Set C is more likely to give wedge failure but even here the average angle of inclination of the intersection of the two planes is 54° at 095°, but may be as low as 40°. Minor planar failure is likely to develop with weathering and aligning of the joints of Set A and B but this is only because this quarry face is excessively steep (80°). The plot shows that the major discontinuity (the bedding) is at right angles to the face and it is because of this happy coincidence either intuitively designed by the quarry operators or as a result of the explosive shattering of the face, that this steep face has continued to stand and not failed.

As the joints of Sets A and B open and the angle of friction of the quartzite deteriorates because of weathering, the likelihood of such a failure increases. Even with the existing face direction the face angle should be lowered to 55° to ensure complete stability.

Line 5

This line (plate 12) was measured above Holloway's crusher near the loading bin. Two sets of discontinuities are present. Set A, (the bedding), dips into the existing face. Set B, a major set of sub-continuous joints has a dip which ranges from 85° NW through the vertical to 85° SE.

The stereo-plot is opposite to that seen on Line 4 and indicates a condition of grave instability. The influence of bedding dipping into the face is well illustrated. If the beds were dipping NW the face would collapse.

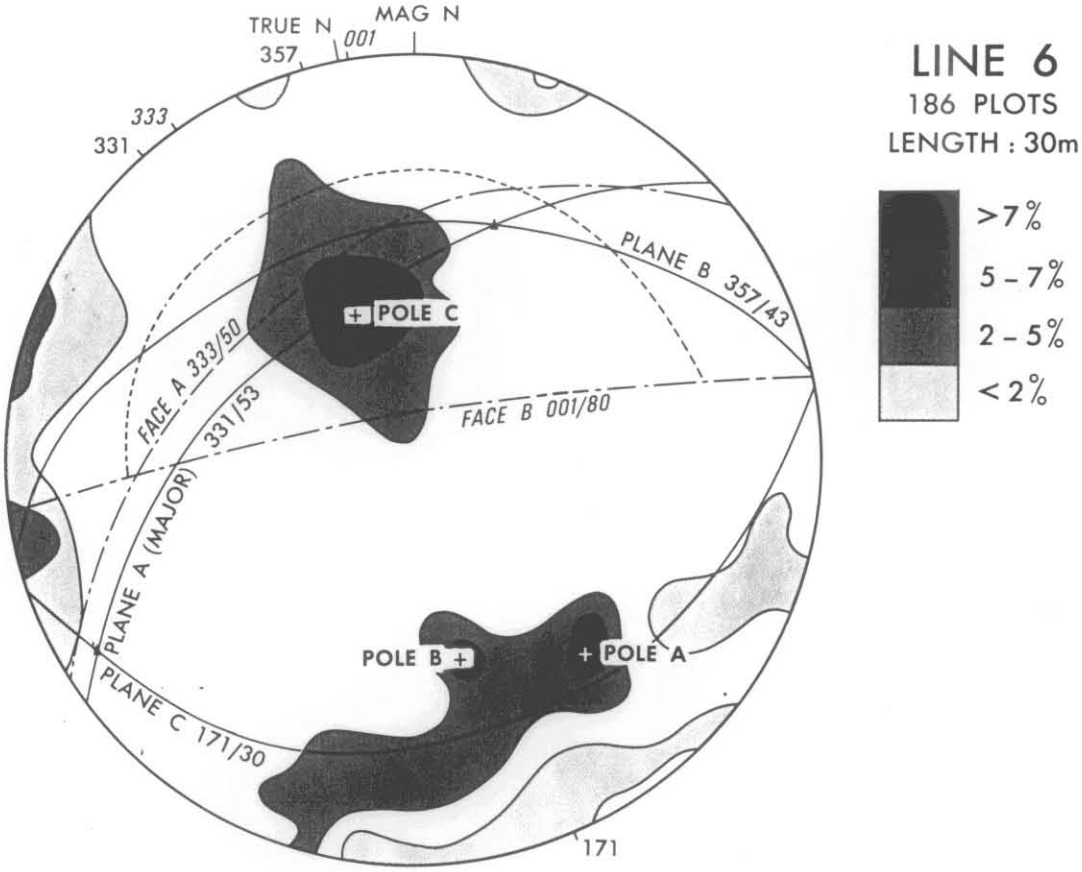
The plots only emphasise what is clear visually and it appeared to the writer that some joints had opened during his successive visits. Movement of these joints should be monitored.

Line 6

This line was measured on the lower of the high tracks of Holloway's pit. The sediments are dominantly cleaved mudstone rather than the quartzite-dominated sequence of the previous sections.

Three sets of discontinuities were present on the stereo-plots. Set A and B are joints and Set C bedding. A fourth set, a widely spread system of major joints, has steep dips of 70° to vertical.

Wedge failures are possible because of the three sets of intersecting joints on face B but the angle of inclination of the intersection of the set of discontinuities is too great for them to surface on face A. This plot



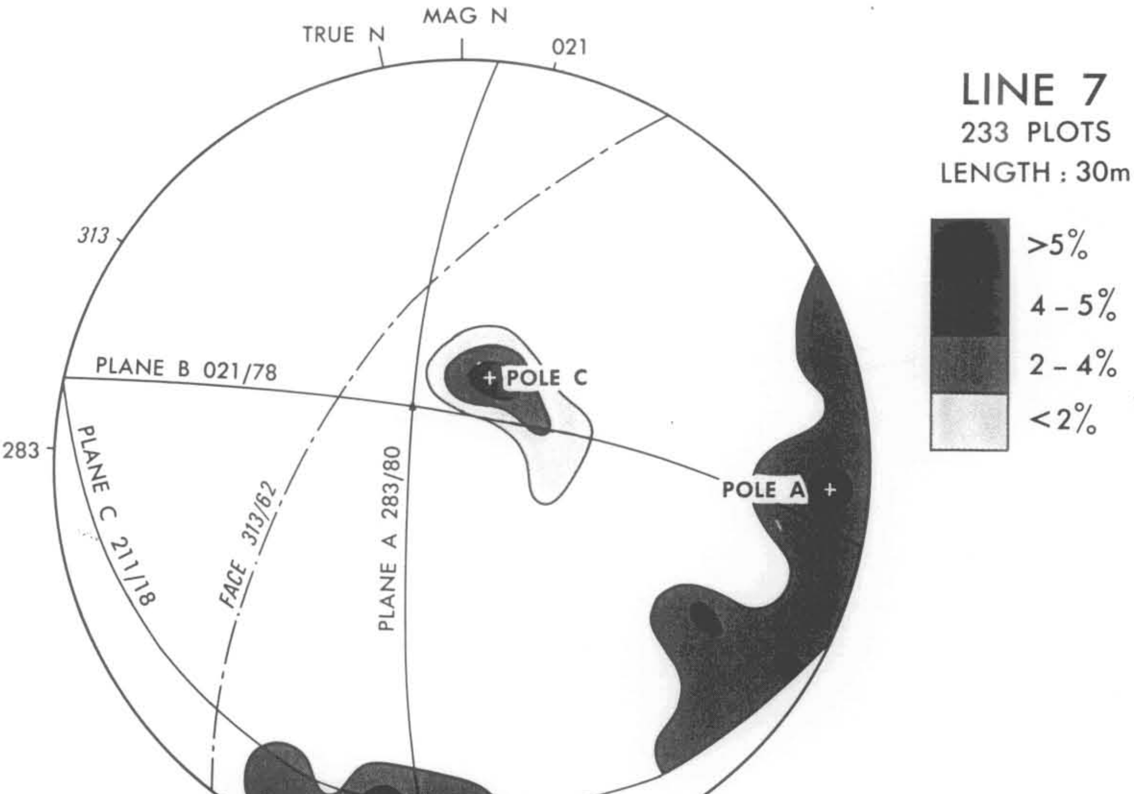


Figure 5. *Structural analysis, Lines 6 and 7*

5 cm

indicates the importance of the face direction in complexly folded sediments.

Because of the highly cleaved mudstone, fretting failure, where the slope disintegrates into small blocks and rubble, is occurring at outcrop. This fretting will probably be so rapid that wedge failures will not occur and the fretting process will lower the face angle so that slope stability will be achieved.

Line 7

This line was measured at the east end of Round Hill. Three sets of discontinuities are visible on the plots. Set A and B are discontinuous sets of joints and Set C the bedding. The two joint sets are widely scattered around the periphery of the plot which allows fretting to occur similar to that occurring in the mudstone although the sediments in this section are quartzite. No wedge or planar failures are likely as the joints dip more steeply than the slope of the face and the bedding dips into the face.

OBSERVATIONS FROM THE SLOPE STABILITY ANALYSIS

Wedge, planar, and toppling failures, and fretting for the slopes on Round Hill can be predicted from the seven analyses undertaken. Examples of all these types of failure can already be seen at outcrop on the limited amount of rock now exposed. Back analyses of these examples fall within predicted failure zones of the plots and verify the assumed angle of friction for the quartzite and slate.

With large rock exposures more likely in future quarrying operations it is logical to conclude that the potential for slope failure will increase.

High stable faces cut at a very high angle are possible and appear stable over a short period of time as seen on Line 4 in Holloway's pit. The structural analyses show that this stability is the result of the face being cut in a specific direction in relation to the major discontinuities. In a complexly folded rock and with so many discontinuities, such stable conditions are not likely to occur over a wide area. This is well exemplified in the stable conditions found in Line 4 whereas Line 5, less than 20 m away, very unstable and dangerous conditions occur.

If quarrying was to continue at its present face direction and angle in Holloway's pit the bedding of the fold would swing and steepen in dip as a result of WSW plunge on this fold as it would pinch out against the NE-SW fault. This would result in a stable face becoming unstable as a direct result of the structural geology.

No attempt has been made to evaluate the part that groundwater plays in the stability of these rocks. That they contain groundwater is shown by the presence of the springs as base of the P.W.D. quarry.

Because of weathering it can be assumed that the angle of friction of the rocks will decrease with time and the initial cohesion of the rock will also decrease. High benches and steep faces may be justified during the short working life of a quarry face but if the public are to have access to the area then lower benches and less steep faces would be needed to ensure long term stability.

CONCLUSIONS

In answer to the three engineering geological questions posed at the beginning of the report:

(1) The geological structure is very important to the stability of the existing quarry faces. As more of the rock is quarried and blasting and pre-splitting techniques are used, the geological structure will become of over-riding importance.

(2) If a general E-W quarry face direction is to be maintained and the unweathered quartzite is quarried on a large scale an overall face slope of 30° will need to be maintained to ensure long-term slope stability.

(3) The maximum bench height should be 8 m and wide enough for access for machinery to clear fallen material (plate 13).

RECOMMENDATIONS

Serious doubts exist if the underlying assumptions of the initial brief are able to be achieved. Clearly an overall slope of 30° with benches as low as 8 m will remove most of Round Hill.

Also the cost of removing the future material, unweathered quartzite, is going to increase sharply. The high cost of removing this rock mostly up dip, using explosives and pre-splitting techniques require stable and uniform geological conditions over a large face area. Such conditions are not present at Round Hill. High cost quartzite aggregate will probably be replaced by better quality material (*e.g.* basalt) because the indications are that the Round Hill material is not ideal for aggregate (Threader, 1975).

The obvious advantage of working the superficial deposit at Round Hill has been its cheapness. This is a direct result of its ease of quarrying. When this factor disappears commercial interest in Round Hill will cease. Local and State Governments will then be left with a disused quarry requiring rehabilitation on environmental grounds.

A possibility for continued limited production as well as some rehabilitation is to allow the small scale production to continue on the stable faces and instituting a programme of benching in which the risks of small scale wedge failures are accepted. If the operators are aware of these failures and the face of the benches monitored the risk can be made acceptable. Such a face will have to follow the geology and will be irregular in direction. Such a scheme pre-supposes that the dangerous face in front of the crusher has been stabilised.

REFERENCES

GEE, R.D.; GULLINE, A.B. *In press*. Geological atlas 1 mile series. Zone 7 sheet 28 (8015N). Burnie. *Explan.Rep.geol.Surv.Tasm.*

THREADER, V.M. 1975. The quarrying of road-making material in the Burnie district. *Unpubl.Rep.Dep.Mines Tasm.* 1975/68.

[1 June 1976]

Plate 1. *Talus deposits, Holloway's western boundary track.*

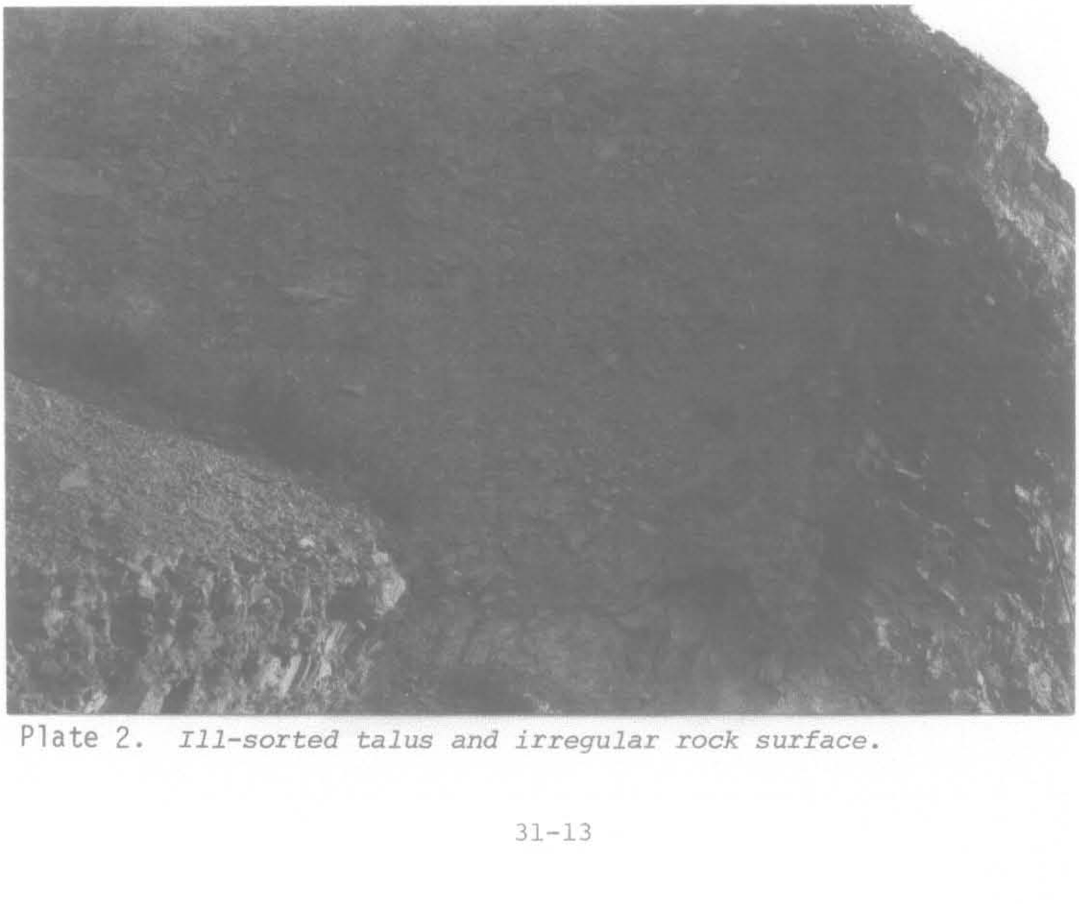


Plate 2. *Ill-sorted talus and irregular rock surface.*

Plate 3. *Thick talus deposits, showing slumping.*

Plate 4. *Talus deposits overlying weathered quartzite and slate.*

Plate 5. *Line 1, showing wedge failures.*

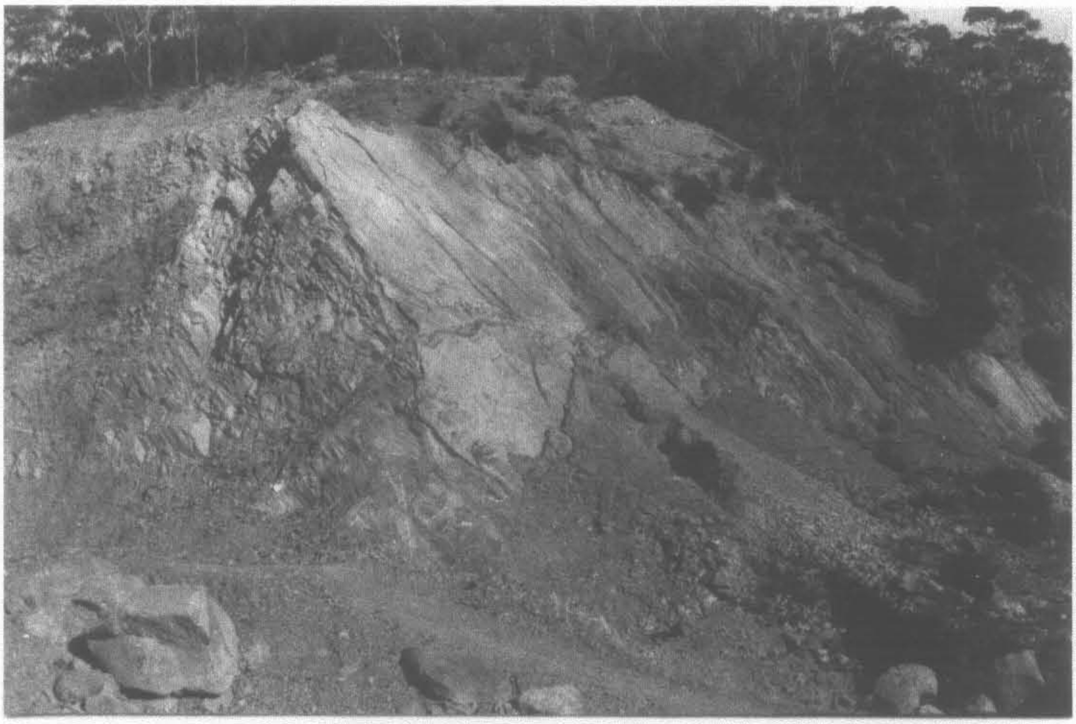


Plate 6. *Line 1, showing planar failure.*

Plate 7. *Line 2a, showing two sets of joints.*

Plate 8. *Line 2b, showing small planar failures.*

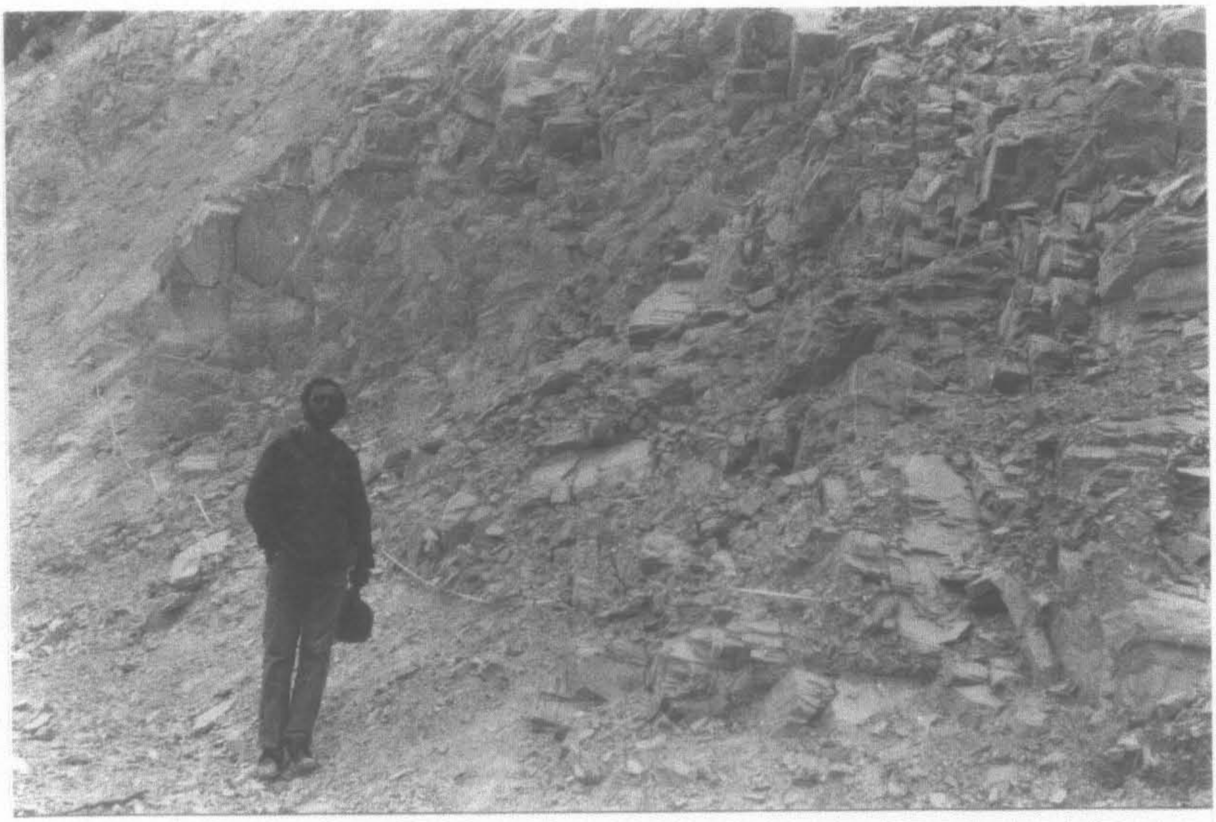


Plate 9. *Line 3, showing two sets of steeply dipping joints.*

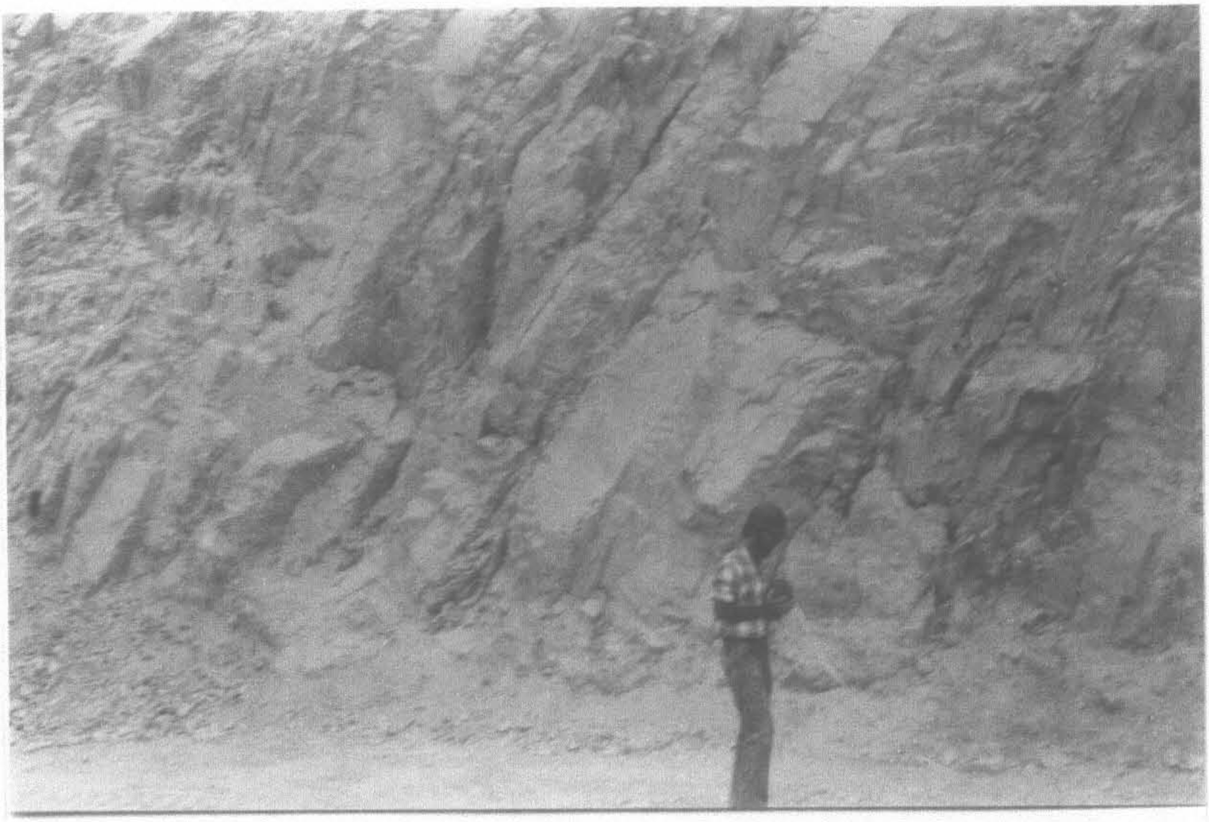


Plate 10. *Line 4, showing bedding.*

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Plate 11. *Line 4, showing fold and fault.*

Plate 12. *Line 5, showing jointing and bedding.*

Plate 13. *Fallen blocks on Wreckair property.*