UR1976_71

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1976/71. Engineering geology investigation of a proposed cutting on the Murchison Highway at Somerset.

W.R. Moore

The Public Works Department (P.W.D.) requested the Department of Mines to undertake a rock stability analysis of a 200 m cliff section of the Murchison Highway at Cam River, Somerset [DQ019553] (fig. 1; plate 1).

This analysis would serve as a guide to the feasibility of the proposal for widening and straightening the existing narrow highway by cutting back this road with a 40 m-high cut having a batter angle of 55° and one 3-metre bench 20 m above the road. On first examination of the cliff section it was apparent that the existing cliff was unstable and that there was a long history of rock falls, some of which were very recent (plate 2). Any further construction would certainly add to this instability.

EXISTING INSTABILITIES ABOVE THE PRESENT HIGHWAY.

A more detailed examination of the face with ropes from the top of the cliff and later from a crane cage revealed three potentially dangerous areas where rock falls were likely. Five monitoring devices have been placed to cover these areas.

Area 1 (plates 3 and 4)

A tension crack about 1-1.5 m long and about 4 cm wide was found on the upper surface in the area of an old wedge failure above measured section 3 (fig. 1). This upper surface tension crack connects with a series of cracks which run from road level to the top of the cliff. These cracks are clearly visible from the road (plate 4). The tension crack on the upper surface of the wedge could not be traced continuously because of the cover of vegetation but isolated cracks were found over the area of upper surface in the position and in the anticipated direction where a large wedge failure will occur. Little imagination is required to visualise the continuous ledges present as having been formed by intersecting tension cracks on which movement has already taken place.

The existence of this tension crack indicates that some movement has already occurred but the time of movement is not known. In time, this wedge will fail and fall. An attempt is now being made to monitor at weekly intervals any movement on this potential wedge in the hope that some warning may be possible before it falls.

Where a tension crack follows one major discontinuity such monitoring devices are normally adequate. In these argillites a discontinuity often follows the bedding of the thicker beds by a series of intersecting cross cracks. This makes it difficult to follow and recognise the major discontinuity along the top of a wedge, especially where vegetation is present on the cliff face. There is therefore a risk that the failure can occur in an area not covered by the monitoring devices.

Area 2 (plate 5)

The second potentially dangerous area is at the northern end of the cliff, above measured section 5 (fig. 1). A planar failure has already occurred along a bedding plane of a thick silty argillite bed when most of the upper limb of a fold fell. The P.W.D. then removed some further material considered dangerous after this initial rock fall. On what appears to be the initial southern release surface of this planar slide are a series

5 cm

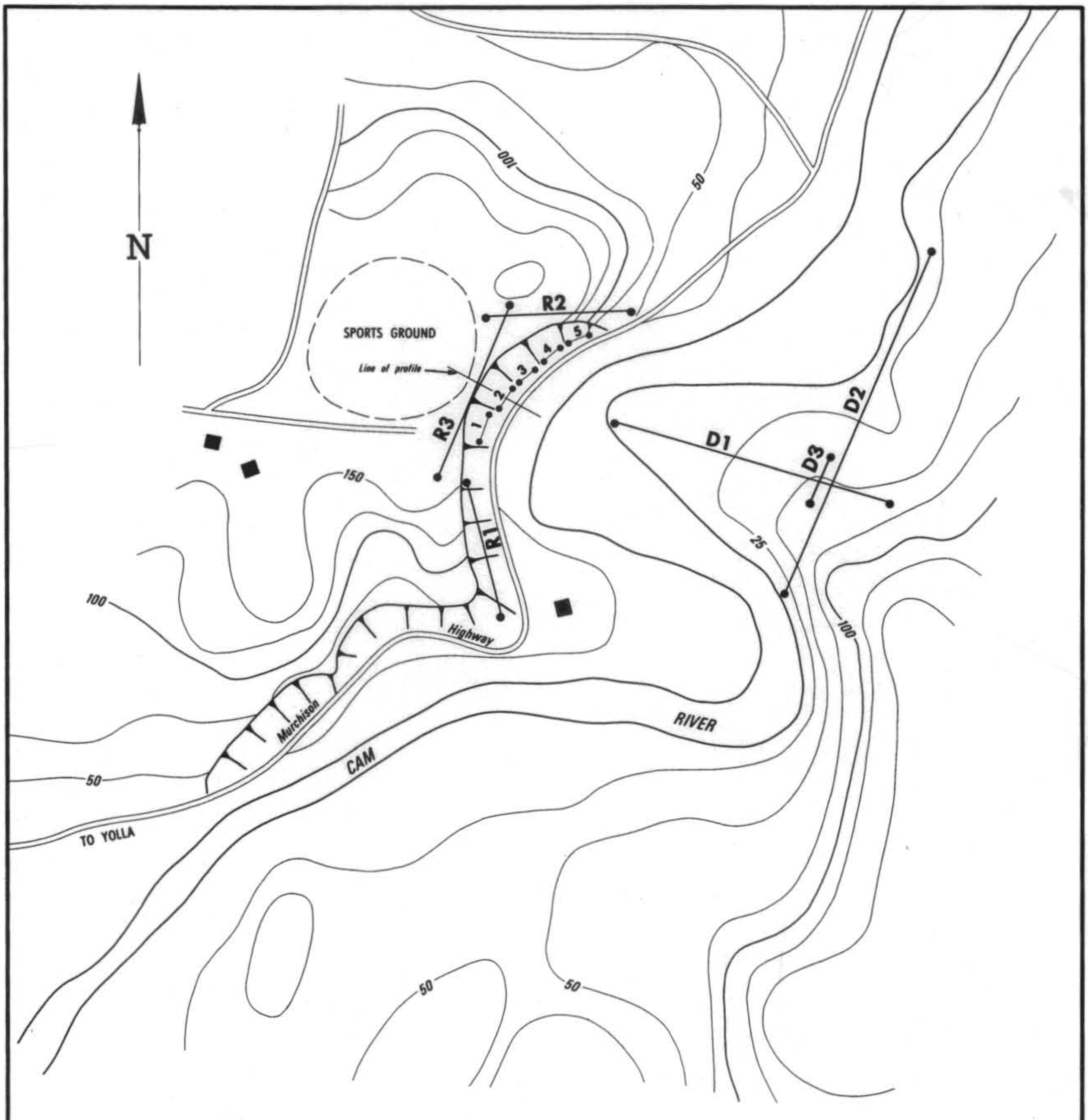
N
SPORTS GROUND
Line of profile
R1
R2
R3
1
2
3
4
5
D1
D2
D3
100
50
150
25
Highway
Murchison
CAM
RIVER
TO YOLLA
Structural analysis
Seismic spread R1–R3 Rippeability survey
D1 and D2 Diversion survey
0
200
400
600m
CONTOURS IN FEET

Figure 1.

of perched slabs or argillite, all badly cracked, and supported on a small slab on the concave section of the fold at the base of the old planar slide. This bottom slab is badly cracked with some cracks opening, showing the rotating movement of the slabs above it (plate 6). A large tension crack is visible along the top of this area immediately below the drainage trench and path at the top of the face. A monitor has been placed on this lower slab, but there is a danger that most of the initial rock movement has already occurred and the next movement will be the final rock fall.

Area 3

This area cannot be seen from the road nor from ropes, and became visible only from the crane late in the investigation, when the monitoring devices were being installed in Areas 1 and 2. It is about 20 m above the narrowest section of the road, above measured section 2. The sediments are deeply weathered and a series of harder silty argillite beds, 1-1.5 m thick, is underlain by 1-2 m thick beds of deeply weathered softer mudstone. Differential weathering of the mudstone has left the harder silty argillite beds overhanging. Large open intersecting cracks running through the argillite appear to produce an inverse wedge type of failure in which falls occur by toppling from the face. Several examples of this type of complex failure are discussed later (Stability Analysis, Section 3). Two monitoring wires were stretched over these ledges in the hope that as the beds tilt forward they will push against the wires and the movement will be recorded by stretching the spring.

Old wedge failures

There are a series of small wedge failures along the top of the cliff face, above measured sections 3 and 4 (fig. 1; plate 7).

In some of these wedges the line of intersection between the faces of the wedge is curved. This is because one face (the bedding) is folded. The wedge is assymetrical and therefore its geometry is variable, giving this type of wedge a ski-jump type of slope at its base (plate 8).

Another series of wedge failures is seen where a major joint intersects a series of thick beds in the argillite (plate 9). These wedges appear to have fallen as a unit, the upper wedge bringing with it the underlying wedges as it fell.

In the case of some of the larger old wedge failure scars visible along the cliff face it is unlikely that the failure occurred as one fall but as a series of falls. This process will continue until a more stable face configuration is achieved, with a lower slope angle and the face direction determined by the structural geology at that particular location (plate 10).

FOLDING AND ITS EFFECTS ON STABILITY OF SLOPES

Although the style of folding exposed in the cliffs (plate 11) will not alter, the position of the folds and the intersecting of joints will change as the cliff face is cut back.

By a selective process of previous rock falls and to a lesser degree by other natural erosional process such as creep and weathering, the existing face has assumed an irregular and stepped appearance with a variable direction of dip. In some areas a high slope angle has been achieved with considerable stability where, because of the folding, the bedding at this location is dipping in towards the cliff (plate 12), but where the bedding has a component of dip out towards the face the area is still unstable even though a much lower face angle has been formed (plate 13).

EFFECT OF FOLDING ON THE DESIGN OF THE FUTURE CUTTING

When the new face is constructed to a simple curve with a constant slope angle this accommodation to the local geological structure will be lost with a resulting overall decline of stability along the face.

Even if a much lower slope angle than that proposed (55°) is accepted small wedge, planar and toppling failures will occur because of the complex nature of the folding. Therefore more than one bench on to which material displaced by small wedge and topping failures and fretting will fall will have to be accepted in the design. This natural wastage will result in a reduction of the width of the benches. The proposed width of 3 m will not be wide enough to allow for this wastage and still allow machines to clear the debris of the anticipated rock falls. The bench height must be sufficiently low to stop the major rock falls but the smaller rock falls (mainly wedge failures) will have to be accepted in the design.

As the amplitude of most of the folds is less than 10 m the adoption of a maximum face height of 10 m should guard against large scale failures. A bench width of 6 m would provide access for machinery with a safety margin to allow for wastage of the edge of the bench.

Small scale toppling and wedge failures, such as can be seen along the present face will still occur.

Debris from small-scale failures can be cleaned up from the benches and rock trap ditch.

The number and height of the benches is independent of the overall slope of the face.

STABILITY ANALYSIS

Although there are some high, steep faces on the present cliff, they should not be taken as a guide to a safe slope angle for a high cutting. The cliff face has not overall reached a stable slope angle. There is ample evidence of previous rock falls and potentially unstable areas.

Stereographic plots of rock discontinuities in the face were made using the techniques of Hoek and Gray (1974) and were compared with plots of failures which have occurred.

By back analysis of the measured failures compared with the predicted failures it is possible to obtain a guide to the angle of friction of the rock which, by definition, is the safe angle of slope for that rock.

In this exercise a range for the angle of friction (25-35°) was used as it was thought that the coarsely bedded silty argillites may have a different angle of friction to the very thinly bedded slates and mudstones.

In measuring the existing wedge failures a discrepancy occurs between the measured and the plotted lines of intersection. Most of this error occurs in measuring these old wedge failures from the road level although some is due to folding of the bedding, which is one of the discontinuities in most of the wedge failures.

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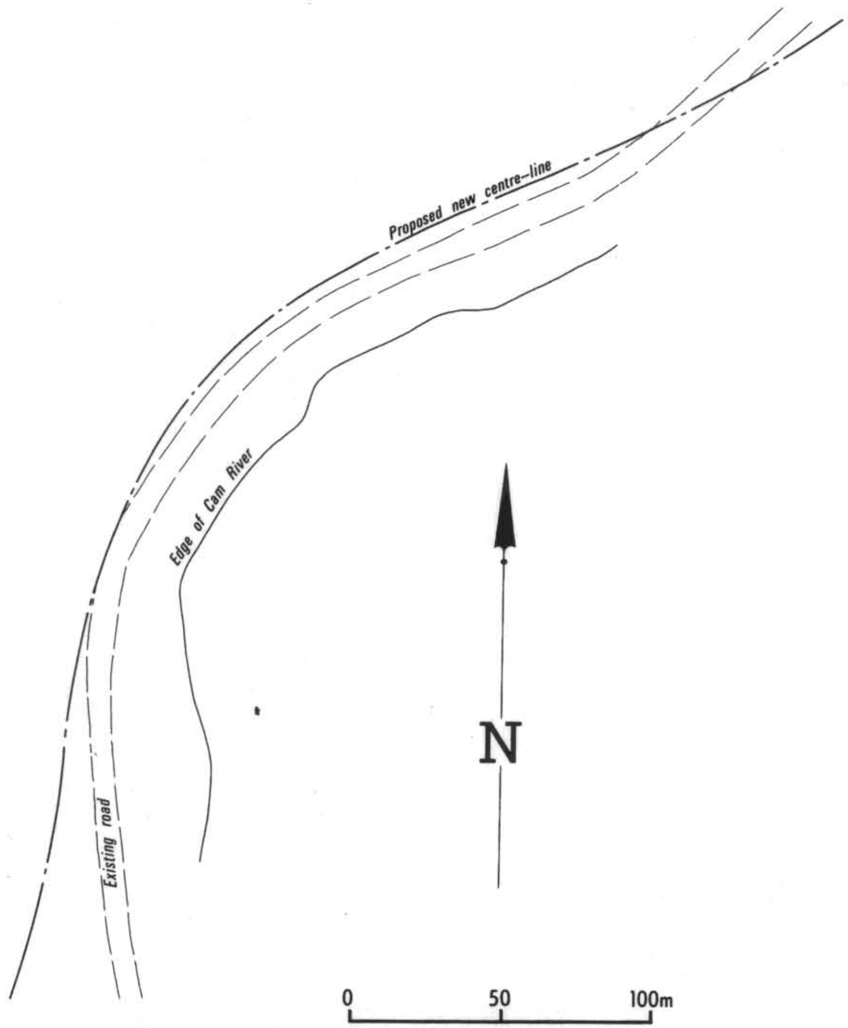

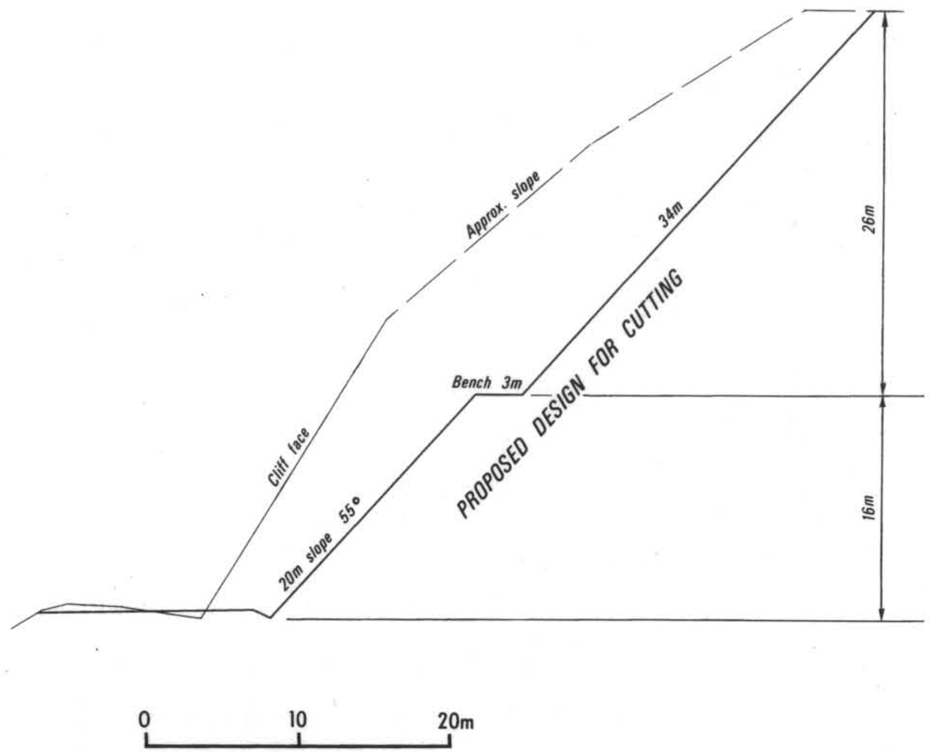

Figure 2. PLAN SHOWING PROPOSED NEW CENTRE-LINE

PROPOSED HIGH CUT PROFILE

5 cm

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Section 1 (fig. 3)

This section was measured on the southern end of the cliff line where the sediments are softer and very thinly bedded. These rocks are more weathered and are better described as a cleaved mudstone rather than an argillite. There are four sets of joints (A, B, C, D) all very closely spaced. The poles of the bedding (X) are not well marked. Wedge failures are made possible by the intersection of two sets of joints (A and D) and toppling failure on set C which has a plot scatter range from 80° through to the vertical.

With jointing so closely spaced and the joint scatter so wide the only failure likely to occur on this section of the cliff line is fretting. This type of failure is present on the cliff face in this area and has already occurred on the new face south of this section (plate 1). No back analysis plot is given as no other types of failure were seen in section 1.

Section 2 (fig. 4)

This section was measured where the coarsely bedded argillites contain many beds over one metre thick (plates 3 and 12). Graded bedding occurs in some beds with silty mudstone and siltstone grading to mudstone. These sediments are highly compressed and have a strong cleavage which produces a well developed foliation at right angles to the bedding giving the sediments a crenulated bedding surface (plate 11).

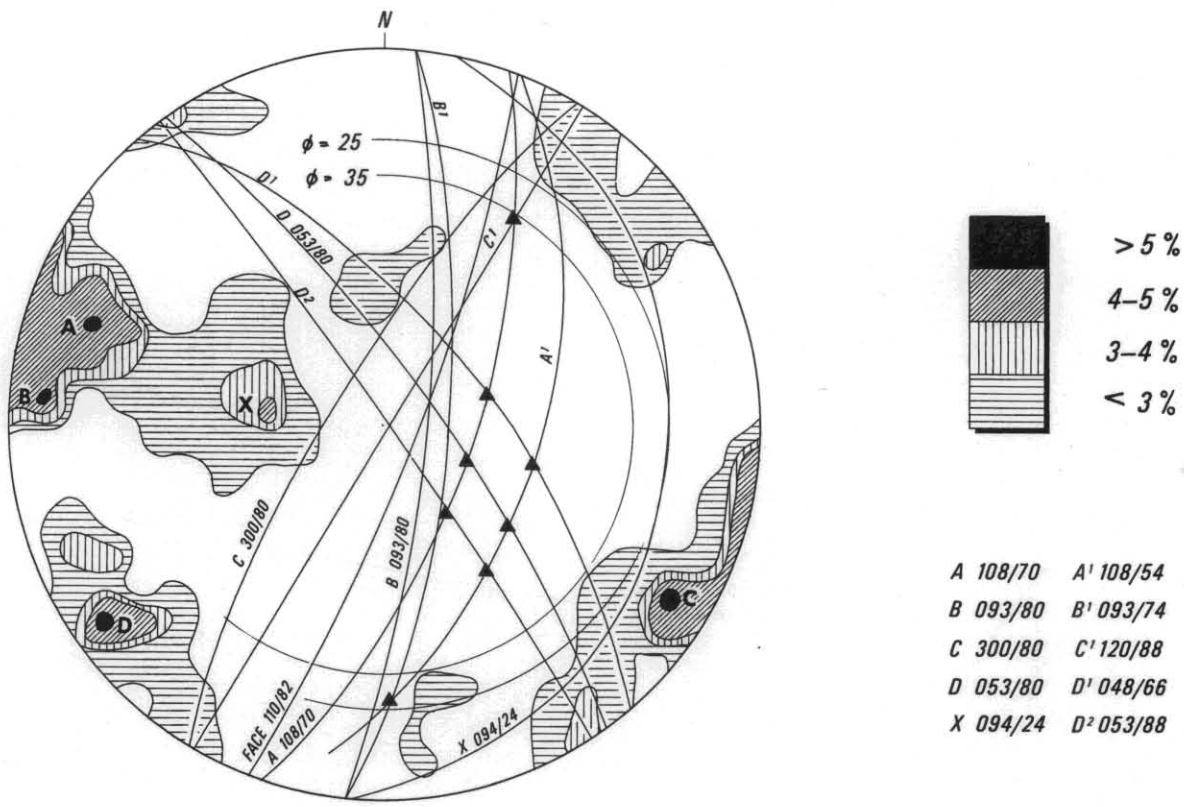
From the measured section plots potential wedge failures are likely to occur at the intersection of the two sets of joints D and F. These wedges are narrow and small, sliding in a south-easterly direction (150°) with a dip on the line of intersection of 50°.

The poles of the bedding are scattered along a belt in the low dip area in the south-west and north-west quadrants of the plot. Any planar failure will occur on the bedding and not on the concentrations of the joint sets A, B and D because the majority of dips on these joints are too steep for these joints to daylight, even on a steep face with an 80° dip. Toppling is likely to occur on set E joints, but only because the existing face is so steep.

In the measured back analyses failures above section 2 there is a close approximation in the direction of sliding of wedge W2 to the direction of sliding of the potential wedg e, although the measured dip on the line of intersection (which is the angle of sliding of the actual wedge) is much lower, 26-30° compared with the 40-45° dip of the potential wedge.

The geometry of the two measured wedges, W1 and W2 is different to the potential wedge of section 2. These measured wedges both include the bedding as a plane of discontinuity, with joint set F forming the other limb of wedge W2, and joint set D in W1. These wedges are wide and open, with low dips on the lines of intersection of their two planes (W1 = 26-33°; W2 = 22-25°) indicating that the angle of friction for this argillite is low. Because of these three properties, such wedges are potentially more dangerous than the narrow and deep type of wedge with a steeply dipping line of intersection (see measured plot, fig. 4). To prevent this large type of wedge failure the slope angle needs to be less than 30°.

It should be noted that wedge W1, slides in a NE direction bearing 060-067° with a dip of 24-26°. This wedge is not seen in the measured plots until section 5. These wedges are not a potential risk in section 5 because



SECTION 1
150 PLOTS

LEGEND

W1M ---------- *MEASURED POSITION OF LINE OF INTERSECTION*

W1P ---------- *PLOTTED POSITION OF LINE OF INTERSECTION*

140/20 ---------- *BEARING OF DIP / DIP*

φ ---------- *ANGLE OF FRICTION*

Figure 3. *Stability analysis, Section 1*

5 cm

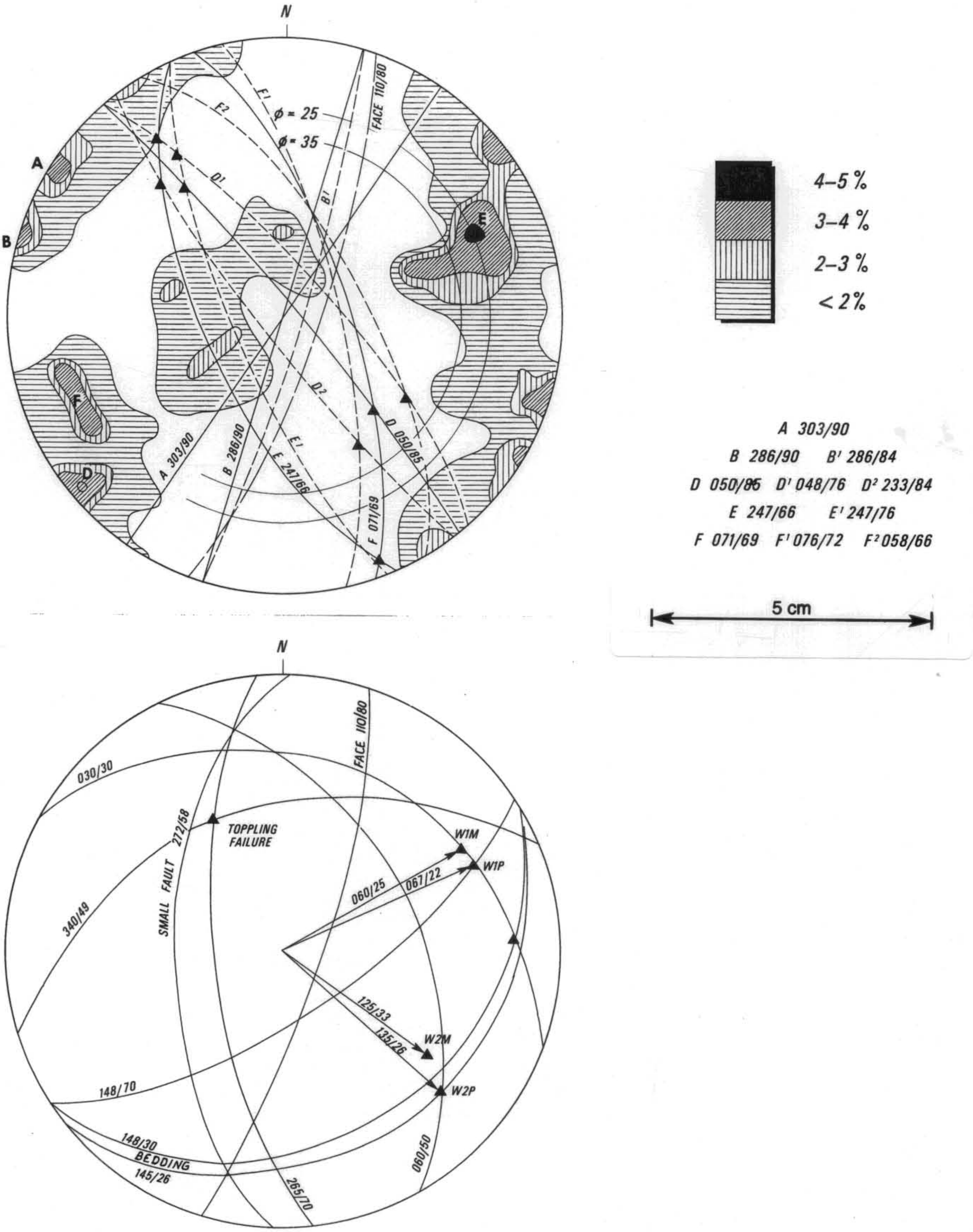


Figure 4. *Stability analysis, Section 2 (226 plots)*

the face direction along the cliff line has swung from 110°/80° to 155°/70°* between sections 2 and 5.

In addition to the wedges, a complex type of toppling failure has occurred above the section on a major joint (265°/70°) which is close to, and parallel with, a fault that passes through this section. This joint is crossed by another joint (240°/49°). Where the joints intersect behind the face an inverse type of wedge toppled and fell from the face. This toppling occurs on a third discontinuity which is very difficult to measure or estimate from the road. This type of inverse wedge toppling occurs in the unstable area 3.

Section 3 (fig. 5)

The lithology and bedding thicknesses are similar to those in the previous section.

From the statistical contouring of the discontinuities on measured section 3 there are three sets of joints A, B and D. Potential wedge failures are possible from the intersection of sets A and B with the line of intersection dipping SSE (158°/40°). These wedges are narrow and small, and even if the scatter of the joints to next lowest percentage subdivision on the plot is included, the bearing of the direction of sliding only ranges from 140-170° and the angle of dip of the potential movement ranges from 35-62°.

Two wedges W1 and W2 were measured above this section on the cliff face. The direction of sliding and the dip of the line of intersection was measured at 125-130°/33°. The two sets of joints in these wedges coincide with joint sets A and B of the measured section, although in the actual wedge failures these joints do not intercept each other to form the wedges but intersect with the bedding. The poles of the bedding in the measured section plots form a scatter belt in the low angle area of the north-west quadrant.

Section 4 (fig. 6)

This section is most interesting because of the potential stability as shown from the plot of the measured section at road level, whereas on the cliff above the section several wedge failures are present (plate 7 and 8) as well as the beginning of a large planar failure (plate 5).

In the stability analysis plots no obvious potential wedge failures can be seen and the dips on joint set B, even allowing for their wide scatter, are too steep to daylight even on such a steep face, for planar failure to be likely. The concentration and position of joint set C makes toppling failure a possibility. Many of these joints are discontinuous and the toppling would be on a small scale and probably of the complex inverted wedge type.

Section 5 (fig. 7)

In the measured section, wedge failures can be predicted as occurring on the intersection of joint sets B and D with the direction of movement to the south-east (122°) with a dip of 55°. Scatter to a 4% concentration can lower the dip of this movement to 50°. Therefore on the proposed cutting with a better angle of 55° many of these wedges will daylight on the face.

*In this report the bearing of the dip direction is given first, followed by the amount of dip. The term 'strike' is not used.

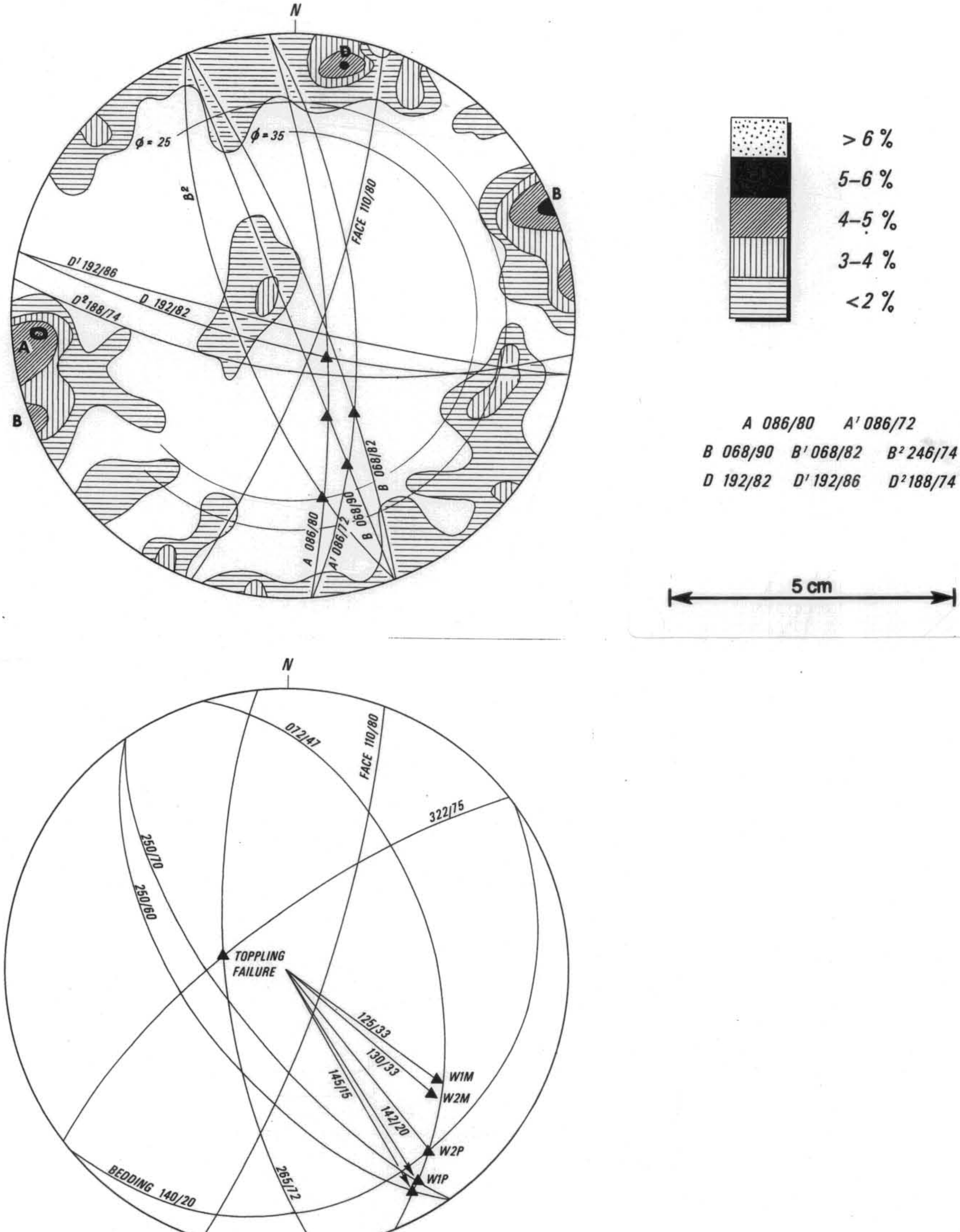


Figure 5. *Stability analysis, Section 3 (183 plots)*

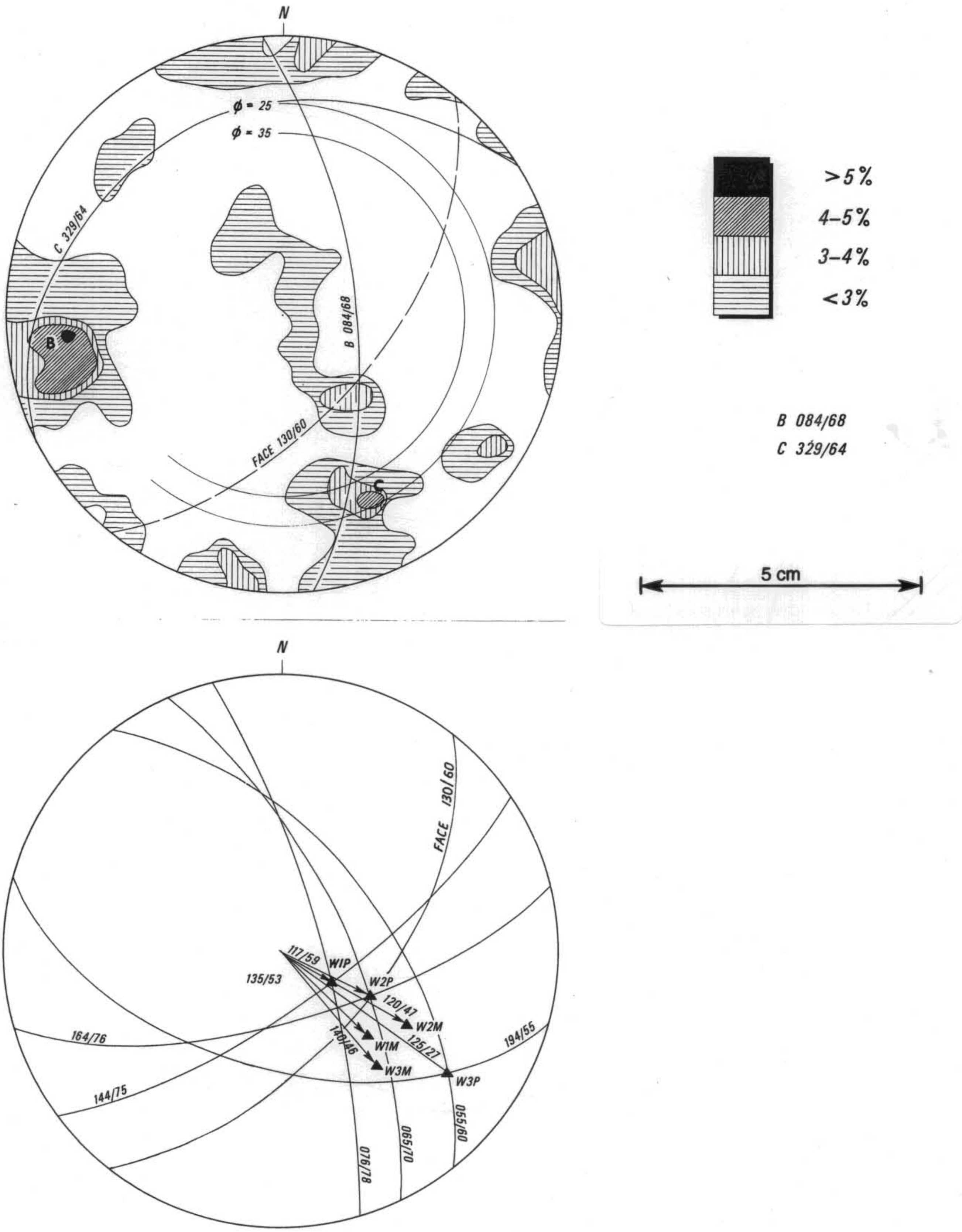


Figure 6. *Stability analysis, Section 4 (168 plots)*

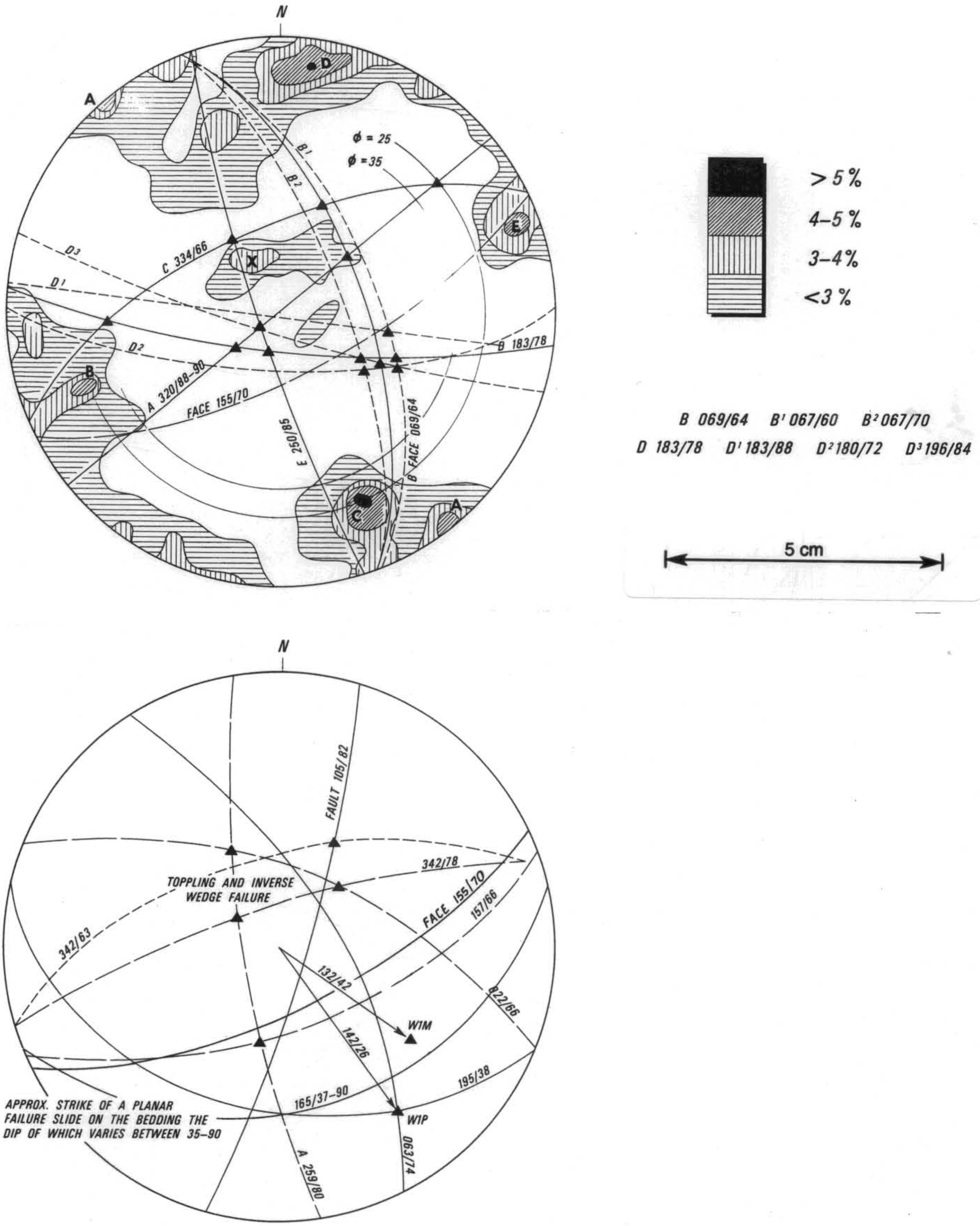


Figure 7. *Stability analysis, Section 5 (162 plots)*

Toppling failures are likely on joint set C particularly when the scatter is considered as the range of dip extends beyond the vertical. Planar failure is not obvious from the statistical contouring until it is realised that the low dipping concentration of 3-4% is the bedding. In the type of folding present at the Cam River the dips of this bedding range from 35-90° in directions into the face as well as away from the face.

Both sections 4 and 5 illustrate the weakness of the statistical approach to stability analysis in areas of complexly folded rocks. Clearly at the Cam River bedding is the major discontinuity on which many failures have occurred and can be predicted as occurring on the new cutting face. Yet because of the thickness of the bedding units combined with the folding, the poles of the bedding do not show as the highest concentration zone on the plots. Therefore the bedding should be artificially weighted. This is difficult because as bedding dip and dip direction range widely poles of the bedding appear as a scatter.

In the back analysis of rock falls seen above section 5 a wedge failure with a measured line of movement of 132°/42° coincides approximately with the above potential wedge position on joint sets B and D. In reality the wedge failure occurred on the intersection of joint set B (063°/74°) and bedding (195°/38°).

The larger planar failure (plate 6) could only be measured approximately from the road and some of the blocks had been removed by the P.W.D. after the initial rock fall. As a result neither the position of the initial failure (the dip of the bedding), nor the position of the release surfaces are known with certainty; this restricts the usefulness of the back analysis, although the angle of friction must be lower than the lowest dip of the bedding which is approximately 35° below the present tension crack on the potential slide. Toppling failures are present above this section on the cliffs where some large blocks have fallen. These are not simple toppling failures but a complex inverted type of wedge failure. One of these failures is associated with a small fault that passes through this section. The other is the intersection of three joints where a large block of rock has recently dropped just above road level. Large fallen blocks are a major traffic hazard, particularly on the narrowest section of the road.

Summary of the results from the stability analysis

(1) Four types of rock fall occur along the existing cliff line. Fretting appears to be the main type of failure in the areas of the new cutting. Lithologically these sediments differ from those in the section yet to be cut. In the new cut the sediments are more thinly bedded and the cleavage is more closely spaced so that they may be described as slate, whereas in the cliff section the bedding is thicker although the bedding planes are well developed, and some silty mudstones are present. The cleavage is strong but is not as dominant as the bedding so that these sediments may be described as argillite. Wedge, planar and toppling failures are more common in the argillite section of the cliff.

(2) The major discontinuity is the bedding in the measured section of the cliff. Bedding combined with another joint set forms the wedge failures. The bedding forms one of the discontinuities in most planar failures.

(3) In the stability analyses a range of 25-35° was assumed for the angle of friction for the argillite. From the back analysis of existing wedge failures, the dips of the line of intersection

for most of the wedges fall within this range. For wedge failure to occur the angle of friction for the rock must be lower than the dip of the line of intersection of the two planes that form the wedge. The lowest measured dip for the line of intersection was 25° measured on Wedge W2 above section 2. Therefore the angle of friction must be less than 35° and could be as low as 25°. If the angle of friction is as low as the back analysis indicates, the immediate question is why is the cliff face standing, when some of the slopes are as high as 80°? However it is clear that:

(*a*) The present cliff face has not attained a stable angle of repose and the face is falling intermittently. There is ample evidence of post and potential failures.

(*b*) The argillites are highly cleaved. This foliation is at right angle to the dip of the bedding and has imparted a crenulated surface to the bedding plane which gives a high cohesion to the rock. When this surface becomes weathered this cohesion is lost and a slide will result.

(*c*) The river is continually eroding the base of the cliff causing the cliff line to retreat. Rock slides of all types are the natural erosional processes by which the cliff line is modified as it is undercut by the river, particularly in times of flood.

This oversteepening of the cliff by the undercutting of its base and the lowering of the angle of the cliff face by rock falls are part of the same erosional process.

CONCLUSIONS CONCERNING THE PRELIMINARY DESIGN HIGH FOR THE CUTTING

Very early in the investigation it appeared, and has subsequently been confirmed by the stability analysis, that the preliminary design for the cutting (fig. 8) is not feasible. In this type of sediment a cutting of this height with a slope angle of 55° with one 3 m wide bench is dangerous and will in time fall down. No allowance appears to have been made for a rock fall pit, the batter angles are far too steep, a single bench is not sufficient and the bench width is inadequate.

However, a safe cutting with a batter angle of less than 35° with four benches 6 m wide would probably be too costly, especially if the rock is not found to be rippable to road level. As well as this cost restraint, there are two other physical restraints to a low batter angle cutting:

(1) The council sports ground close to the top of the cliff.
(2) The Cam River at the base of the existing cliff which is actively eroding the fill on which much of the existing narrow highway is built.

ALTERNATIVES TO THE PROPOSED DESIGN CUTTING

As construction of the new highway has already started at the southern end of the cliff there appears no acceptable alternative route except by a bridge to the eastern bank avoiding the cliff. If the cliff route is to be used then the diversion of the Cam River to obtain space for a lower angle cutting should be considered.

If the river is diverted through a channel at the base of the meander, then the road cutting could be constructed at the lowest possible angle (say

45°) with three or four benches 4-6 m in width. This would also allow space for a rock fall pit and warning fence to cope with the small wedge and planar failures that will occur. The highway will then be built on fill pushed into the river.

This scheme may only be feasible if the argillite exposed on the face is rippable to road level, if the flats enclosed by the meander of the Cam River are formed of soft alluvial sediments and if these sediments are deep enough to allow the river to be diverted without any heavy construction being required.

To give a preliminary guide as to the feasibility of this scheme two seismic surveys were undertaken.

SEISMIC SURVEY

Rippability study

Three spreads were fired around the cliff line (fig. 1, table 1). The first was fired on a bench on a cutting that had already been ripped by bulldozers. This spread was used as a control because the district engineers reported that ripping had become very difficult at the northern end of this bench.

Similar velocities were found on all spreads (table 1). The stepped character of the time-distance plot indicates that certain beds are harder and will be difficult to remove by ripping and the limited use of explosives will be required. This would be anticipated in these strata, in which thicker and harder beds of silty argillite are interbedded with softer slatey mudstone.

In these sediments seismic velocities are lowered by open or sprung joint and bedding planes and therefore serve only as an approximate guide as to rippability. The attitude of the bedding will also influence their rippability.

If any investigatory diamond drilling is undertaken behind the face of the cliff the holes should be pump tested using two hydraulic packers to indicate if the jointing is open, and at what distance back from the face. Also up-the-hole seismic studies should be undertaken as a further guide to rippability.

Alluvial flats

The location of the three spreads is shown on Figure 1 and the results in Table 2. From the velocity of the surface layer (760-1000 m/s) and its calculated thickness of 10 m it appears that no heavy construction will be required for the diversion of the river. A suspected weathered zone with a velocity of 2300-2440 m/s overlies the unweathered argillites for a further 19 m depth in Spread 1 and it appears to be likely that this softer rock will allow the Cam River to deepen its bed along the diversion cut. There is no evidence of the presence of unweathered rock at shallow depth below the bed of the river at this locality.

In the weathering spread (D3) two surface layers were found (V_0 = 300 m/s; V_1 = 1060 m/s). The thickness of this upper layer was about 2 m and if this layer is the coarse sand found in the shot holes in this area and is proved to be very extensive it may be worth stockpiling and selling to offset some of the cost of the diversion. This surface layer in the

Table 1. SEISMIC RESULTS FOR THE RIPPABILITY SURVEY (SPREADS R1-R3).

Spread	Location and direction of spread	Length of spread *(m)*	Geophone interval *(m)*	Seismic velocities *(m/s)*	Symmetry of time plot	Character of time plot	Remarks
R1	N-S. Along bench of a cutting south of cliff line	100	8.1	V_0 760-1050 V_1 2140-2440	Symmetrical	Very highly stepped with velocities as high as 3500-4000 m/s recorded for 3 geophones	At northern end of spread difficulty was experienced in ripping the sediments. A step and a higher velocity (V_1 = 2440 m/s) were recorded.
R2	E-W. On steep slope at northern end of cliff face	113	8.1	V_0 760-910 *West end* V_1 1520-2130 *East end* V_1 2140-2440	Assymetrical	Small steps in V_1 layer	V_0 velocities and thickness influenced by steep slope on the ground surface.
R3	N-S. Along cliff. Top path near the sports ground	145	8.1	V_0 910 V_1 1220-1520 V_2 2140-2590	Symmetrical	V_2 layer very stepped with velocities as high as 4500 m/s for 3 geophones	V_0 layer of red soil overlying weathered rock zone (V_1).

Table 2. SEISMIC RESULTS FOR THE ALLUVIAL FLATS (SPREADS D1-D3).

Spread	Location and direction of spread	Length of spread *(m)*	Geophone interval *(m)*	Seismic velocities *(m/s)*	Depth to interfaces *(m)*	Symmetry of time plot	Character of time plot	Interpretation
D1	E-W. West SP at Cam River bank. East SP cliff base east bank Cam River	145	8	V_0=1000 V_1=2300-2400 V_2=3500-4600	V_0/V_1 7.6-11 V_1/V_2 19.5-23.1	Symmetrical	Stepped in V_2 layer.	V_0 Alluvial sand and gravel etc. V_1 Weathered argillite (rippable) V_2 Unweathered argillite (unrippable)
D2	N-S. North SP at old bridge abutment. South SP at river bank south side of the meander.	145	8	V_0= 760-1000 V_1=1830-2440 V_2-3050?	V_0/V_1 6.1- 9.4 V_1/V_2 Not calculated	Assymetrical slope up to south. V_1 Thicker at N end.	V_1 stepped. V_2 is possibly only a step (recorded only at 3 geophones at S end of spread)	V_0 Alluvial sand, gravel etc. V_1 Argillite and slate (rippable)
D3 (Weathering spread)	N-S. In rubbish dump.	30	1, 2	V_0= 300 V_1=1060	V_0/V_1 2 m	Symmetrical	-	Coarse sand layer seen in shot holes.

weathering spread was not taken into account in the calculations of the two long spreads as it would not greatly affect the calculated depth of the interface between alluvial sediments and argillite.

Before the proposal for diverting the river is accepted further detailed seismic work followed by drilling along the position planned for the cut should be undertaken.

RECOMMENDATIONS

(1) If the original proposed design for the cutting is adhered to extensive rock bolting and even tension cabling of critical areas will have to be contemplated to meet the safety requirements necessary above a major highway. In these folded rocks no guarantee could be given that even after such a programme had been undertaken that unstable areas will not develop. Another difficulty is even after an extensive drilling programme with a high percentage of recovery of orientated cores it would still be very difficult to estimate how much rock bolting and cabling would be required. Such a programme could only be estimated after the face is cut, which makes preliminary feasibility costing most difficult.

(2) Alternatively the slope could be lowered and the river infilled, with, or without a diversion cut. Either scheme would require detailed surveying followed by drilling a line of diamond drill holes at the angle of the proposed cut to road level. Although the style of folding is not likely to alter throughout the area these holes will require orientated and continuous coring and down-the-hole surveying so that bedding dip and direction can be determined. When the holes are completed water pressure testing and up-the-hole seismic studies should be undertaken. If the river is not to be diverted, then protection measures for stopping the undercutting of the fill by the river would be essential. If the diversion is to be made, then a detailed seismic grid on the course of the diversion followed by control drilling should be undertaken.

(3) If a bridge is contemplated a seismic survey using a hydrophone cable should be undertaken across the river as well as preliminary feasibility drilling on the abutments and possible pier positions.

CONCLUSION

As the proposed high cut is considered dangerous, other alternatives should be investigated. All these alternatives appear very costly. All schemes require further investigation including some preliminary design work and surveying followed by a further investigation which should include more geophysical work and a limited amount of diamond and rotary drilling. Only when this has been completed can a feasibility study of the alternative schemes be of any merit.

REFERENCE

HOEK, E.; BRAY, J.W. 1974. *Rock slope engineering*. Institution of Mining and Metallurgy : London.

[20 December 1976]

Plate 1. *Cliffed section of the Murchison Highway, above the Cam River, Somerset.*

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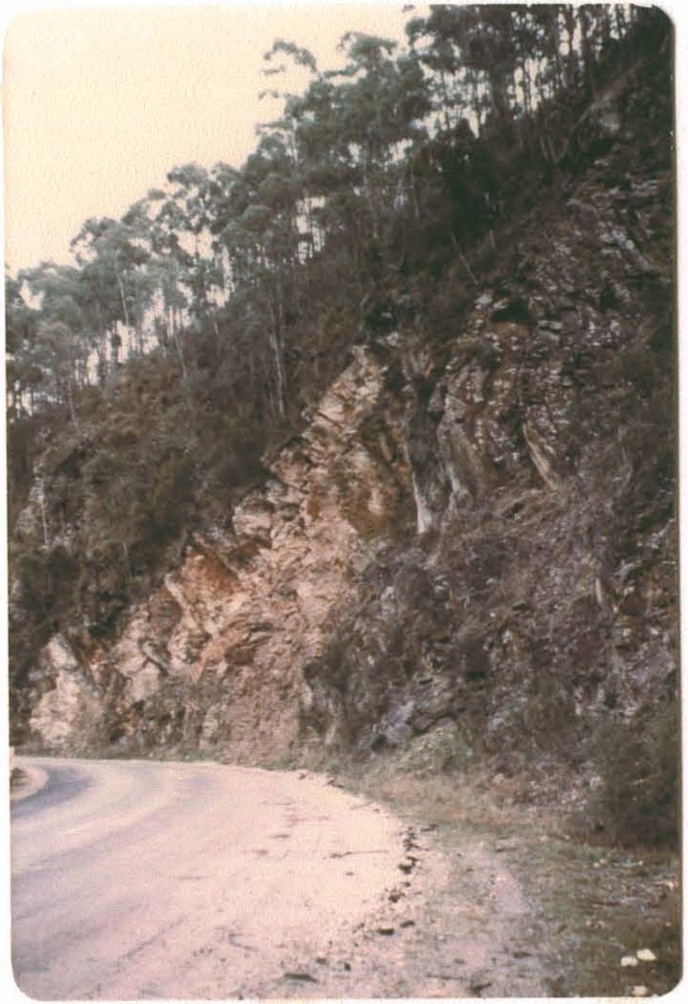


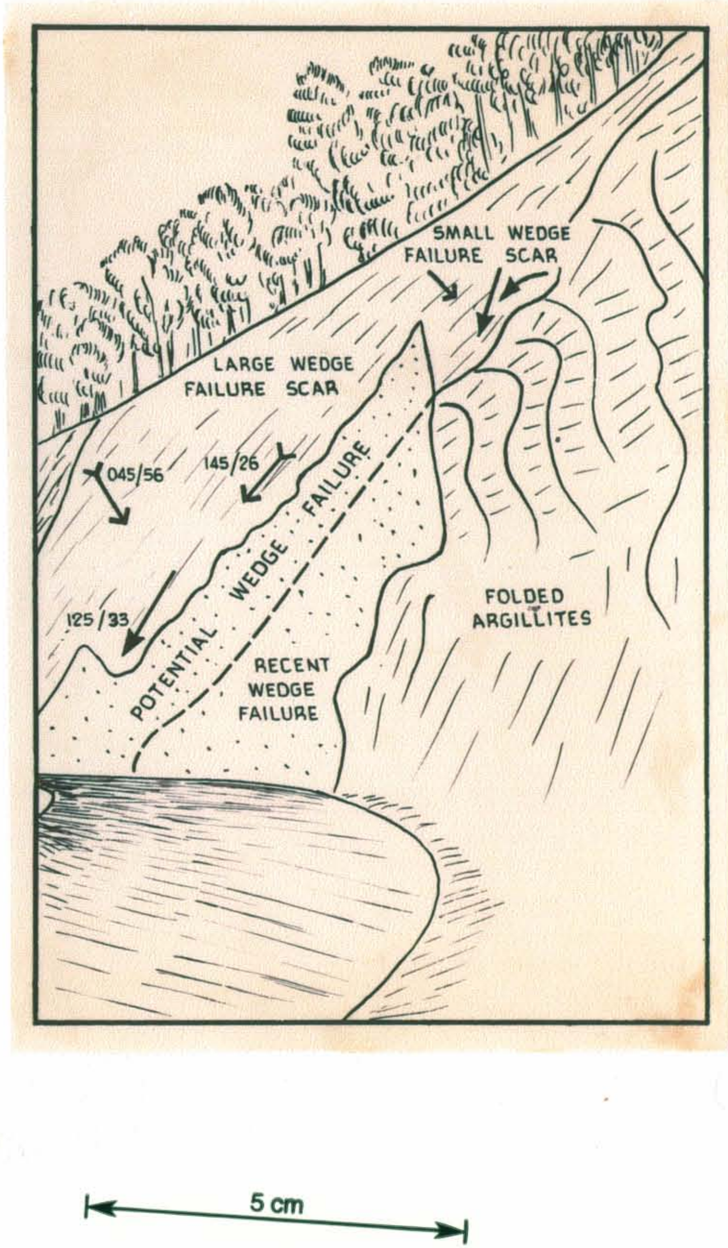


Plate 2. *Previous and potential rock falls*

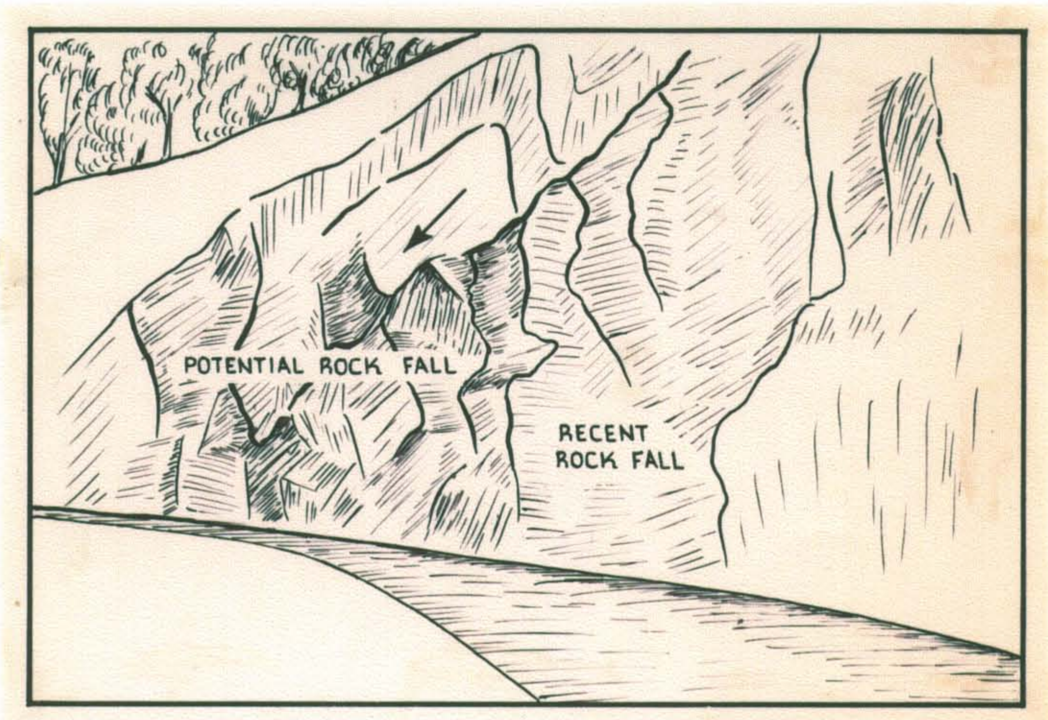


Plate 3. *Potential large wedge failure with tension cracks visible on upper and side face.*

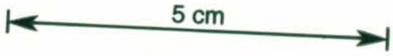
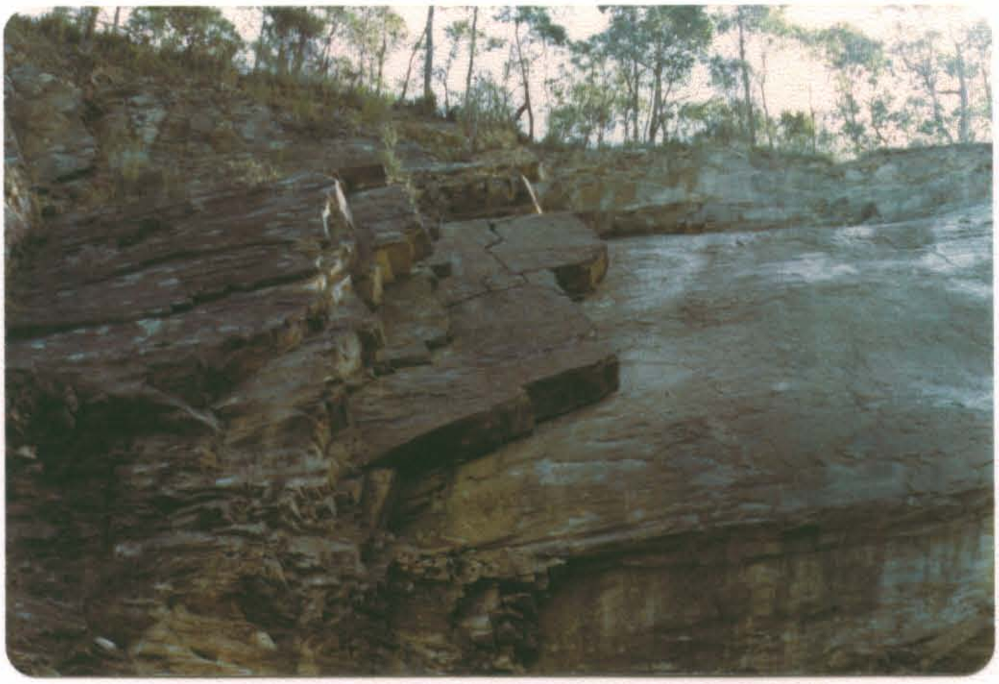


Plate 4. *A series of interconnected cracks along joints and bedding forming a continuous line of weakness from road level to the top of the cliff.*

Plate 5. *Planar failure along the bedding plane on an upper limb of a fold.*



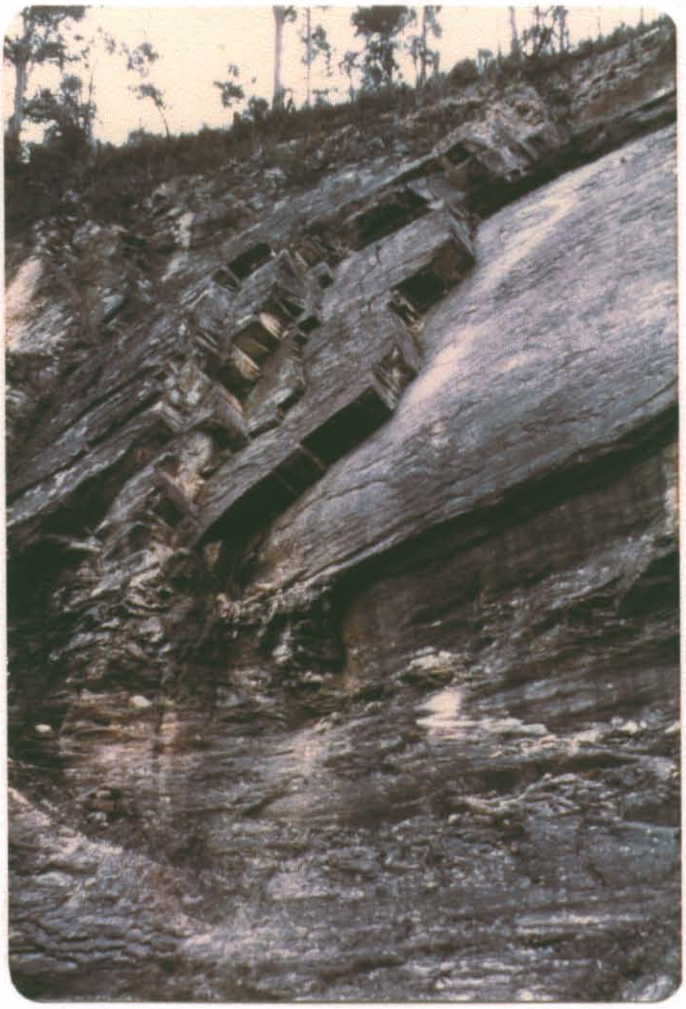


Plate 6. *Series of perched slabs held by bottom cracked slab.*

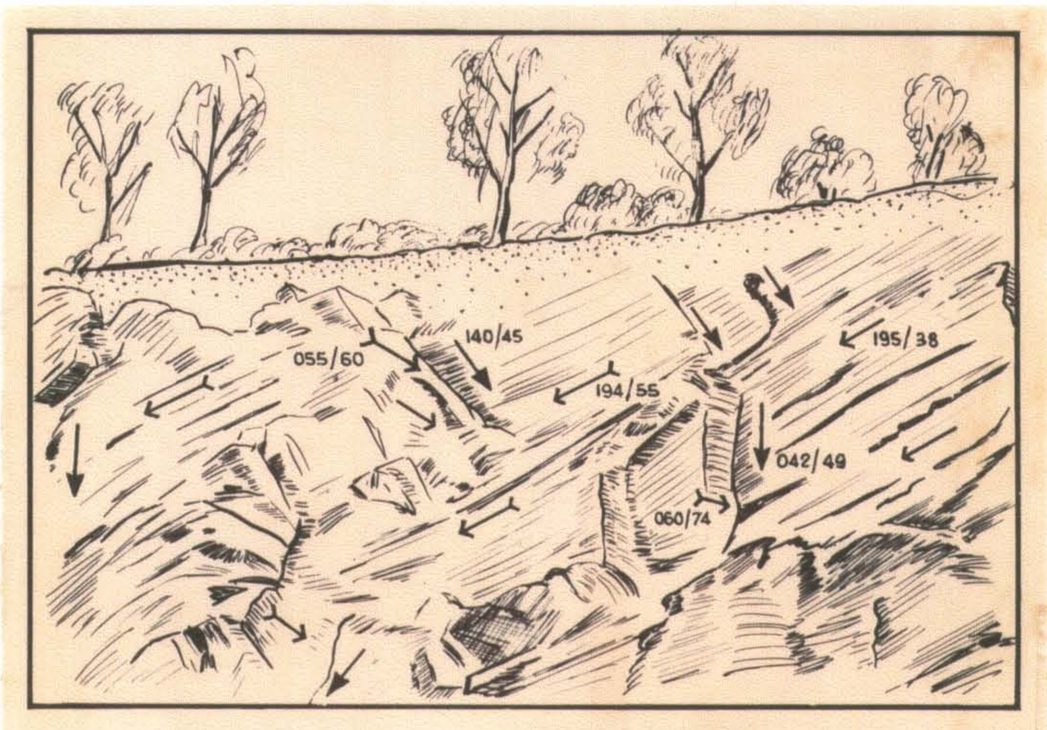
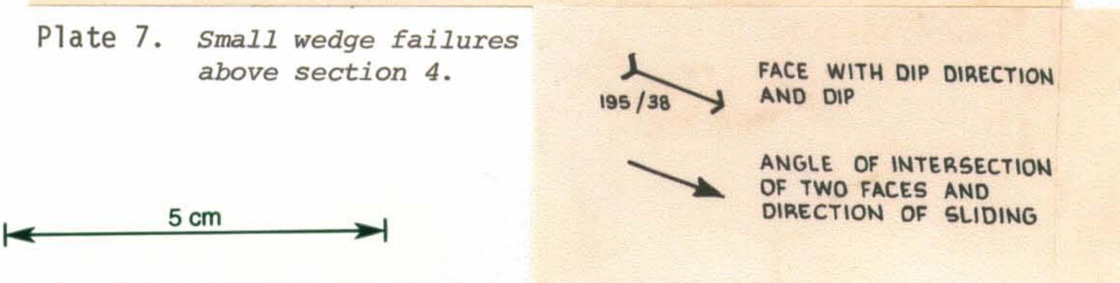


Plate 7. *Small wedge failures above section 4.*



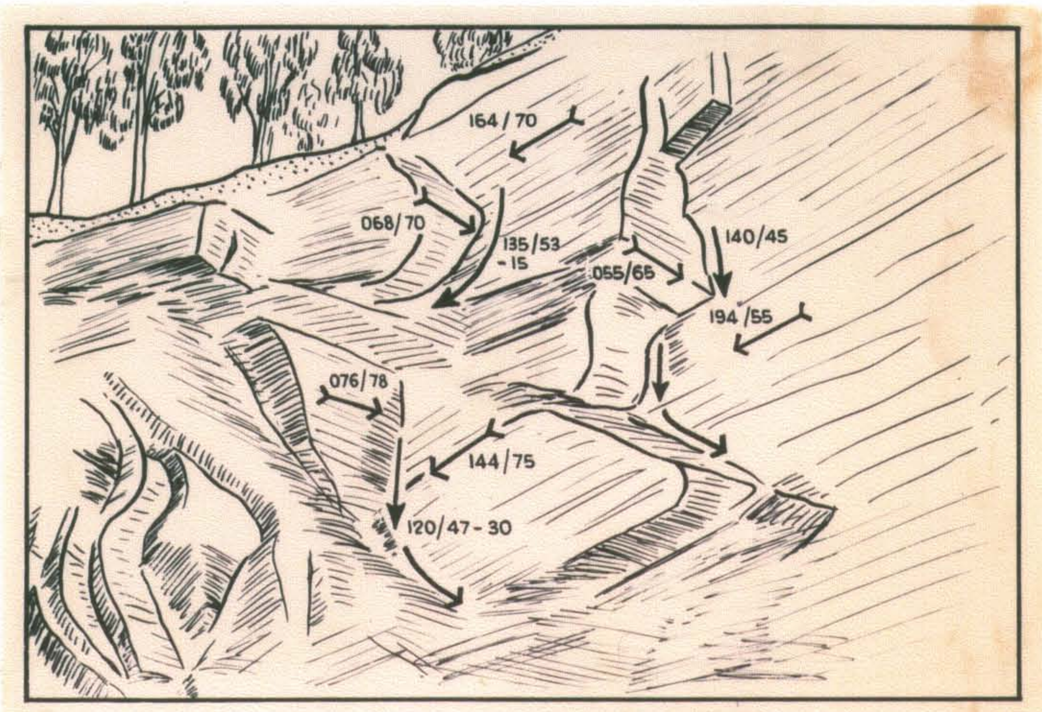


Plate 8. *Small wedge failures with curved line of intersection and low angle of inclination for the direction of movement of the wedge. This curved line of intersection is the result of folding of the bedding (one of the discontinuities of the wedge). Above sections 3-4.*

5 cm

Plate 9. *Wedges which have failed on a major joint dipping NE, and three bedding planes forming a large wedge failure unit.*

Plate 10. *A large wedge failure scar built up by a sequence of failures along NE-dipping jointing and bedding.*

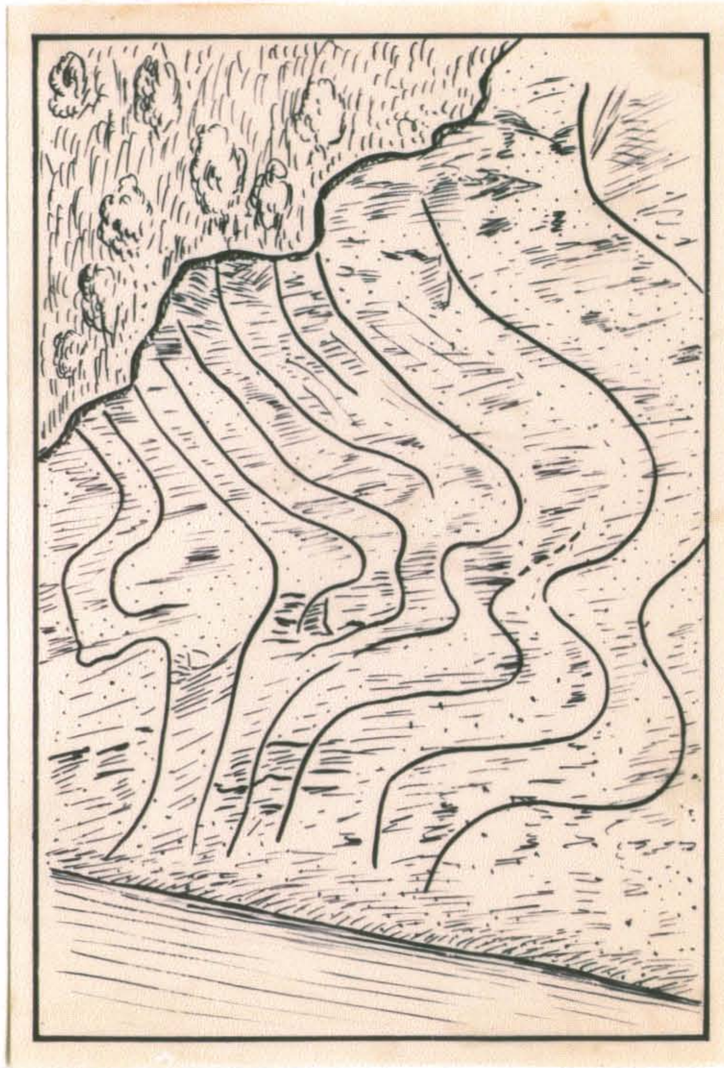
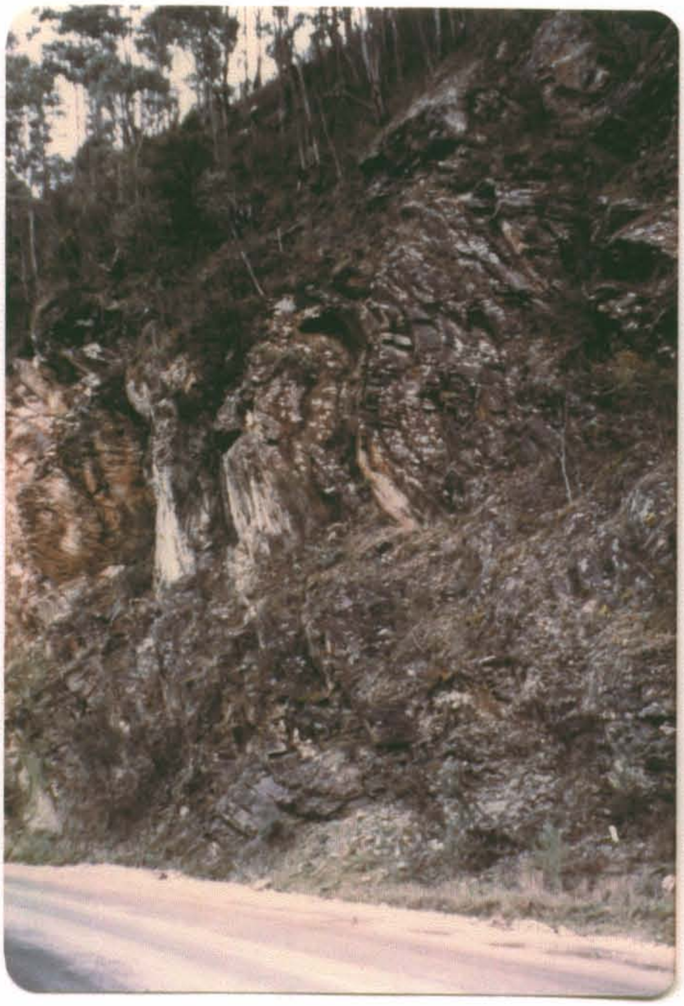


Plate 11. *Style of folding in the argillite showing complex wedge failure in the contorted and crushed zone in the nose of a fold.*

5 cm



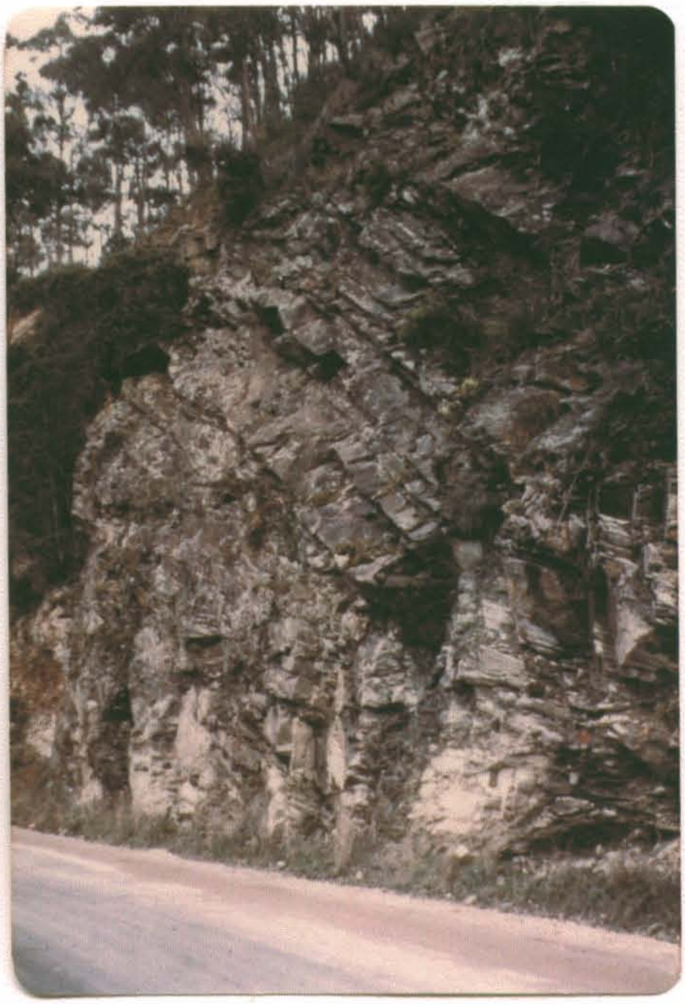


Plate 12. *High face angle and local stability due to the bedding having a dip component away from the cliff-face.*

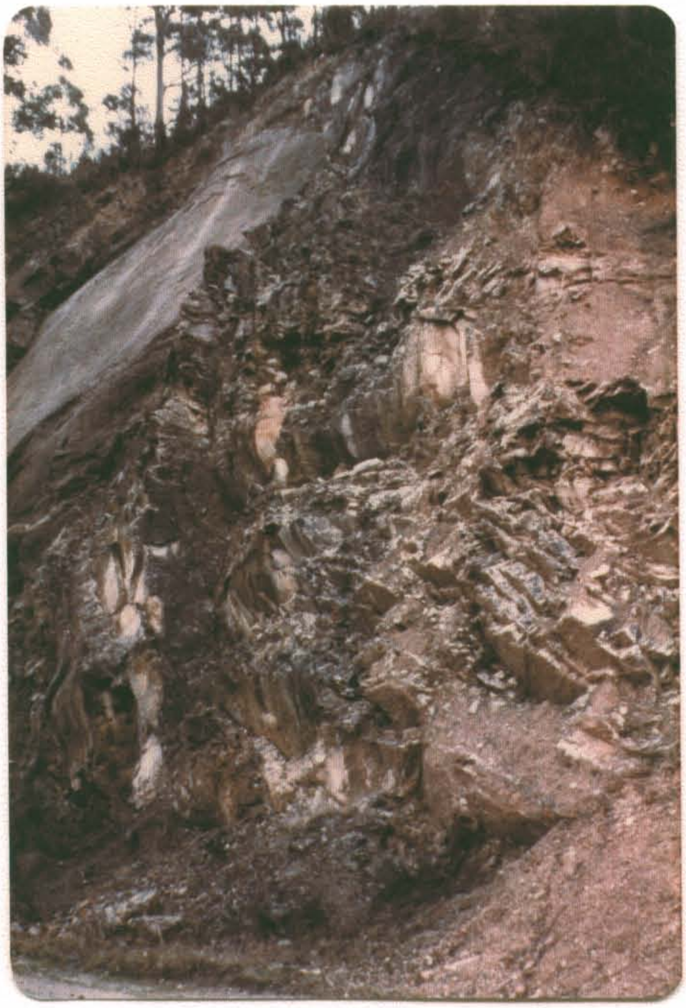
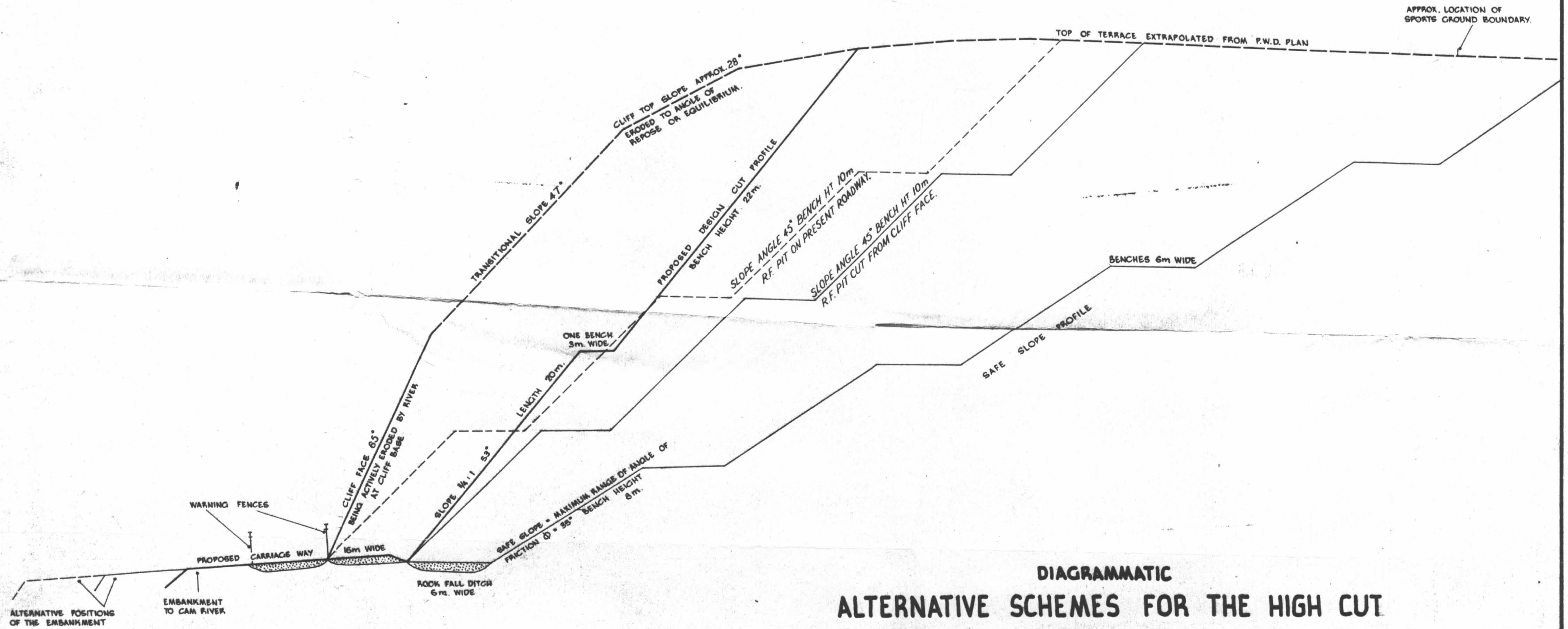


Plate 13. *Bedding with a component of dip towards face resulting in a lower face slope angle, and instability leading to wedge and planar failures.*

Plate 14a. *Well developed cleavage crenulation across the bedding surface.*

Plate 14b. *The largest of a series of small faults (105°/82°) along cliff face (section 5).*



DIAGRAMMATIC

ALTERNATIVE SCHEMES FOR THE HIGH CUT CAM RIVER

(BASED ON PROFILE 1113 -5 x 34 P.W.D.
WARATAH HIGHWAY, SOMERSET - YOLLA CLIFF SECTION)

5 cm

4236 - 28

FIGURE 2.