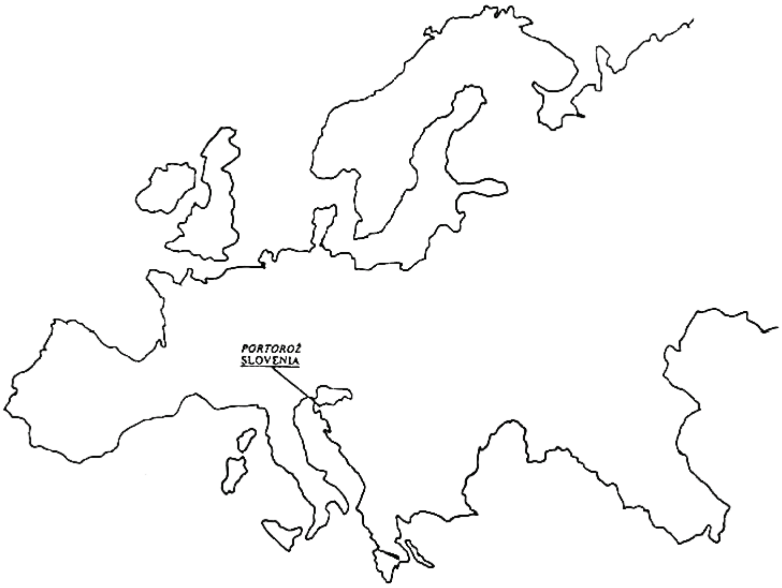
W O R K S H O P

ENGINEERING IN KARST



Portorož, Slovenia
September 7 - 9, 1996

During the IMWA 1996 Workshop, fourteen national and international colleagues presented their experience about engineering and mining in karstic regions. The papers presented were not published in a proceedings volume, but handed out to the delegates as paper copies.

This PDF is one of those documents provided to the delegates.

All other papers can be downloaded from www.IMWA.info

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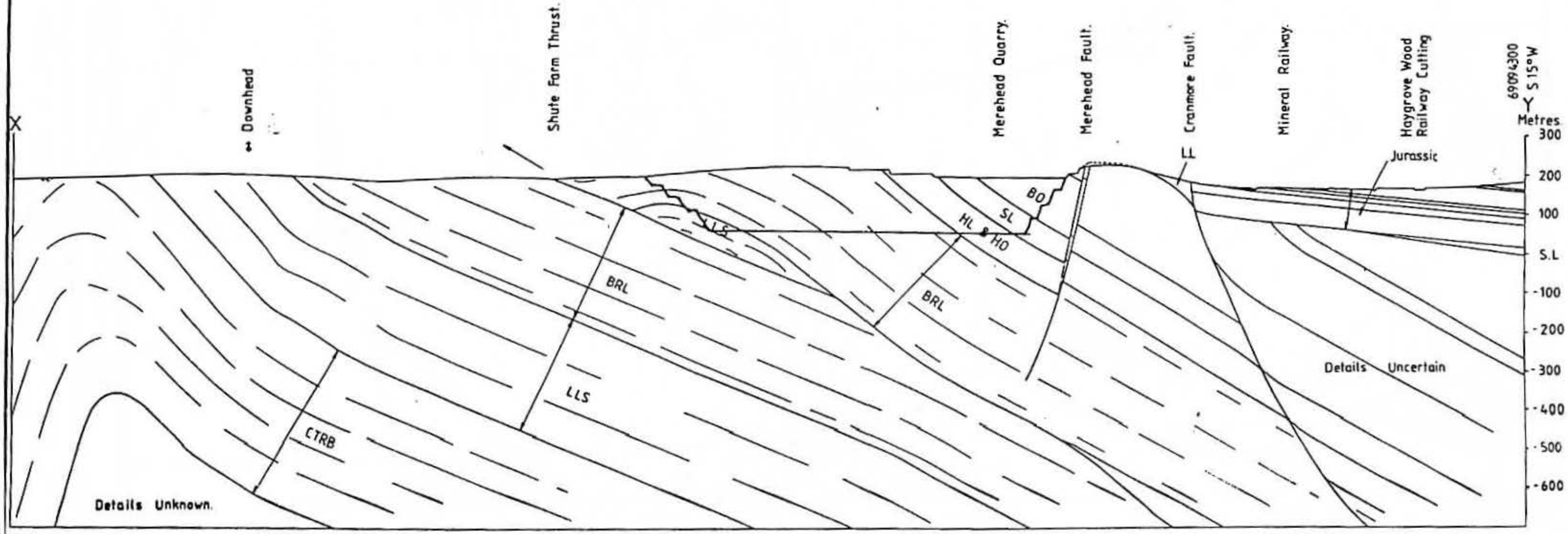
Torr Quarry ~ Foster Yeoman

SLOPE STABILITY STUDY



Legend

CTRB	Cranmore Tower Red Beds.
LLS	Leigh Limestone Shale.
BRL	Black Rock Limestone
HL	Hotwells Limestone.
H.O	Hobbs Oolite.
SL	Splintery Limestone.
B.O	Barnclose Oolite
L.L	Lithostrotion Limestone.

SCALE 1:10000

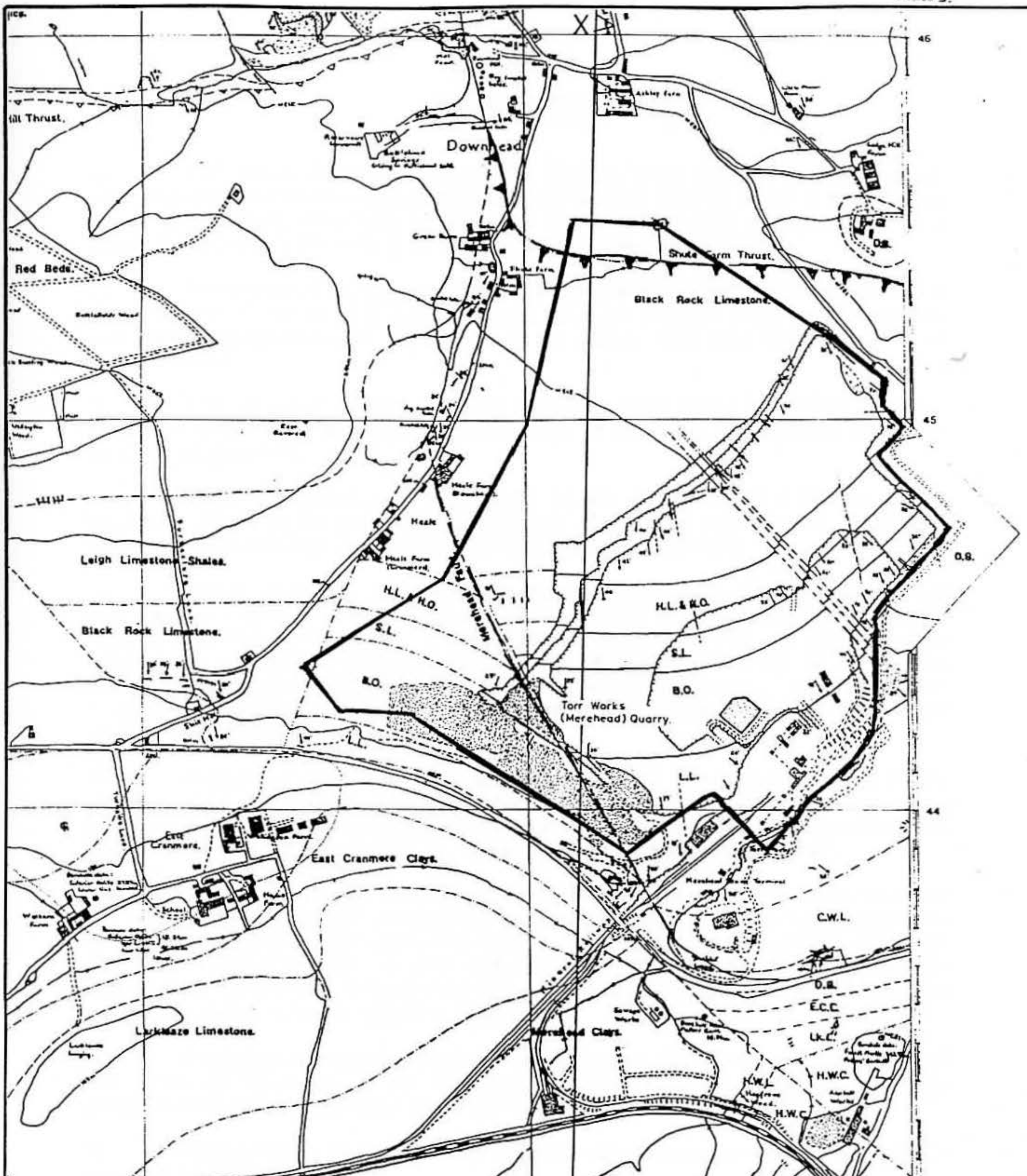
PROJECT

TITLE

CONJECTORAL GEOLOGICAL CROSS SECTION XY.

P J Norton Associates

DRAWING Nº



PROJECT SLOPE STABILITY STUDY - FOSTER YEOMAN.

TITLE GEOLOGY OF AREA ROUND TORR WORKS QUARRY (AFTER VINCENT)

500 250 0 metres

1000 500 0 feet

P J Norton Associates

DRAWING No

CHAPTER II

BACKGROUND

1. Torr Works Quarry is excavated in Carboniferous limestone. Variable but very thin soils and head material overlie the limestone, except in the extreme east, where a consistent unconformity divides it from the overlying Jurassic rock. The latter thins towards the middle of the worked out area and disappears.

2. The proposed extension involves most of the remaining marketable stone in the sequence, there being a stand off from the lane through Heale and Downhead and roadside properties. A major fault to the west of this road forms the limit of the limestone.

3. The sequence extends in depth, such that stone could be worked to below mean sea level. This assumes the satisfaction of stability, hydrological and stone quality requirements.

4. Delays in negotiating acquisition of the land for the extension had a knock-on effect in the current investigations. However it was decided to proceed with the slope stability study while these negotiations continued.

5. Other work has been carried out simultaneously with this study and provided data for it. Foster Yeoman in-house drilling and contracted drilling, both fully cored, has taken place. Foster Yeoman is carrying out the surveying and logging. In addition hydro-geological studies are being carried out by Aspinwalls, who have conducted similar work for Foster Yeoman previously (since 1983), and this has a direct bearing on the work. Noise and vibration studies and landscape studies are also being undertaken.

6. Foster Yeoman staff have recorded much of the geological data of the quarry during the course of normal work. In addition various studies have been carried out, all of which serve to provide base data for this work. These studies, and the other sources of information for the work, are listed at Appendix "A".

7. Over recent years, following land acquisition, the quarry has been "squared up" into an approximately rectangular form. Main features of the working are the sump development in the south, this being a legal requirement, and the change in 1984 to the use of a mobile crusher and conveyor system to replace the dumptruck fleet. Main features of the previous and present operations, which affect the final slopes, are detailed in subsequent sections.

8. A subsidiary consideration for Foster Yeoman, but a factor forming part of the terms of reference, is the design of the blasting and excavation layout on intermediate walls to minimise costs while providing maximum safety.

9. Photograph 1 shows the full sequence of excavation operations and the material being worked.

CHAPTER III

GEOLOGY

GENERAL GEOLOGY

1. A background knowledge of the local geological setting is considered necessary fully to understand the situation pertaining within Torr Works Quarry. Apart from the theory of potential thrust zones in the quarry, the desk study revealed no new information. As no previous report at Torr Works Quarry appears to have covered the geology in much detail, an account of the geology in the vicinity of the quarry is contained in this Report. Although most of this material was presented in the Interim Report of March 1988, it is included here to provide a complete record. The material being worked and the general competence of the strata where the beds dip into the high walls can be seen in Photograph 2.

2. Torr Works Quarry lies at the south-east end of the Mendip Hills and within Carboniferous Limestone zones exposed on the eastern and southern limits of a large fold, known as the Beacon Hill Pericline. The strata excavated in the quarry, and exposed from north to south, are generally agreed to be the Black Rock Limestone (zone d_1 of the Carboniferous Limestones) upwards through the Clifton Down Group (d_2) and the Hotwells Limestone (d_3), as shown on the Geological Survey Sheet 281 and described in the accompanying "Memoirs for Bristol and Gloucestershire District and the Wells and Cheddar District". In the eastern-most part of the quarry face an unconformable layer of Jurassic inferior oolite lies on top of the inclined Carboniferous Limestones. The sequence is shown on Plate 1.

3. The underlying beds of the lower limestone shales and the Portishead beds of the Devonian upper old red sandstones outcrop to the north of the quarry. To the west of the quarry a NNE - SSW trending fault, known as the Downhead Fault, upthrows the limestone shales and the Portishead beds which form the high ground to the west, known as Beacon Hill. To the south of the quarry the Cranmore Fault (Thrust T_1) exposes the Jurassic strata once again and to the east the limestone series continues to be exposed until a capping layer of Jurassic occurs to the east of a deeply incised river valley known as Leighton Hanging. Elsewhere an occasional, thin covering of glacial Pleistocene deposits occur which are known locally as "Head". The geology of the immediate area is shown on Plate 2.

4. A more detailed interpretation of the area immediately surrounding, and within, the quarry and proposed extension has been prepared by Vincent (1988), and is presented on Plate 3. The legend is on Plate 4, which represents a north - south section (XY) through the area.

5. A brief description of the relevant strata, in ascending order, is given below.

DEVONIAN SERIES

Portishead Beds (locally Cranmore Tower Red Beds)

6. These beds, of upper old red sandstone age, outcrop to the west of the Downhead Fault. They are mainly composed of red, micaceous arkosic sandstones, sometimes well bedded with occasional coarse conglomerates. Their significance with regard to Torr Works Quarry is that they are relatively permeable and form the high ground and hence provide a source of groundwater.

CARBONIFEROUS SERIES

Leigh Limestone Shales

7. These strata form a transitional sequence from the coarse landward deposits of the Devonian to the marine incursion of the Carboniferous era. They outcrop to the north of the quarry and abut against the Downhead Fault. They are relatively impermeable shales with occasional limestone bands and give rise to spring lines along their junction with the Devonian strata. This spring line occurs roughly along the line of the 235 m contour line to the west of Downhead village and is used as a source for several domestic water supplies. The rock is described as being a highly fossiliferous green-blue calcareous shale with occasional limestones. The sequence isthe quarry the Cranmore Faul structurally incompetent and is a likely zone for faulting and thrusting.

Black Rock Limestone

8. This series represents a further deepening of the seas during early Carboniferous times and the rocks become more predominantly bioclastic limestones. The rocks are highly fossiliferous with some slight silicification of the strata. Fossil identification is described as being excellent and, as the group forms the major part of Torr Works Quarry, this fact may become important in identifying bedding plane thrusts in places where changes in the facies represent the only way of proving bedding plane movement. The rock also contains some persistent shale bands which are significant from a stability point of view.

9. It is worth noting here that the major stratigraphical zones and structural discontinuities within the strata can only be properly identified from paleontological evidence. Insufficient data currently exist for definite structural identification.

Clifton Down Group

10. This group exhibits considerable facies variation and can be split locally into six specific zones:-

- Lithostrotion Limestone
- Lithostrotion Oolite
- Burnclose Oolite
- Splintery Limestone
- Hobbs Oolite
- Halcombe Limestone.

11. How many of these distinct facies variations are present at Torr Works Quarry is not known but the Geological Survey mapping suggests they are present in the southern part of the excavation. The Lithostrotion group and splintery limestones are described as being predominantly micritic lime mudstones.

Hotwells Limestone

12. Hotwells Limestone, locally known as Cook's Wood Limestone, forms the uppermost bed of the limestone series and its occurrence has been suggested in the eastern wall of the quarry. It is described as being a massive grey crinoidal limestone with oolites and calcite mudstones near the base.

CHAPTER IV

GROUNDWATER

GENERAL

1. A thorough understanding of the groundwater situation is vital to any quarry design exercise. Control of the water table through judicious pumping is the most important single item that a quarry operator can do to improve stability.

2. The groundwater in the area has been the subject of a major study by Aspinwalls (1985 and 1986) on behalf of Foster Yeoman and it is the intention, in this Report, to address that information to the mine design at Torr Works Quarry. From a mining point of view the nature of the groundwater and volumes of water expected are not great. However, if the wrong course of action were taken to deal with it, there would be unnecessary problems and considerable extra expenditure involved. Correct control of groundwater can lead to large savings in costs for other quarry operations such as excavation method, direction of working, blasting, vehicular maintenance, pollution, lagoon design and materials handling.

3. There are two basic methods of dealing with water in an open excavation; by "passive" means as in the present method of allowing the water to collect freely in an in-pit sump or; by active methods, where the collection of water is designed into the overall pit configuration and controlled by borehole pumping outside the working area. To enable the latter to be successfully planned prior to excavation, a thorough hydrogeological investigation is necessary. This has already been achieved and an estimation made of the groundwater inflow quantity and directions at the various potential pavement levels in the deeper extensions to the quarry.

4. The information so far gained in the hydrogeological survey suggests a groundwater gradient dipping gently to the east, as shown on Plate 6. Occasionally, it is stepped over impermeable fault planes such as the Downhead Fault with a drop of 50 m and minor faults within the quarry environment. The groundwater table is at its highest in the Portishead Beds to the west of the Downhead Fault where it issues at springs at about the 230 m level. These springs then cross the impermeable Leigh limestone shales in a series of streams until they disappear below ground in a series of "slockers" in the limestone which crops to the east of the fault. The water then percolates down to the water table at about the 170 m level on the eastern side of the fault.

5. Prior to the sump pumping in Torr Works Quarry the groundwater, depending on seasonal variations, gradually dipped to around the 140 m level in the Asham Wood areas to the east of the quarry. The groundwater drops away to a level of 132 m at Seven Springs and the eventual outflow control level of 112 m at Holwell Springs.

6. This fluctuation in water table is important from a slope stability point of view and Table I shows a summary of groundwater level results to date. Graphs of these groundwater results have been prepared by Foster Yeoman.

7. As can be seen from this table, the seasonal fluctuations in water table height is quite high, especially in the west wall of the quarry (16 m at $Torr_1$ and 13 m at $Torr_6$) and even higher in the unquarried strata beyond the proposed new high wall (20 m at Shute Farm and 25 m at Pound Cottage).

8. The borehole water levels within the quarry have been regularly monitored by Foster Yeoman staff. The results for 1987 are presented in Plate 7. Certain boreholes in the vicinity of the quarry have been similarly monitored and the results are plotted at Plate 8. The locations of all these positions are as shown on Plate 6.

9. It appears that because of the increased amount of clay infilling in the joints and cavities at the southern and western end of the quarry, the groundwater flow rate is less and quite marked fluctuations in water table height in the slopes can be expected. At the northern end there appear to be more void space and solution cavities and the flow is hence much quicker; here less fluctuation in water table is expected. A major conduit must exist between Shute Farm and Seven Springs. It remains advisable to ascertain the depth of this conduit so as to allow for inrushes of water.

10. Because there are both conduit and diffuse flow in the strata there are some anomalies where the large conduits occur and where faulting acts as a barrier. However, the proposed orientation of the high wall suggests that it is unlikely that water will build up behind to a degree that will seriously impair stability, as long as an active dewatering system is implemented, prior to any subsequent excavation to the deep.

11. Further discussions with Aspinwalls suggest that the overall aquifer may only be 50 m thick.

QUARRY DEWATERING

12. Hobbs (1988) in his thesis (not yet published) suggests that the total outflow of the catchment area for Torr Works Quarry is about 6 Mm^3/a. This represents the regional flow of water under equilibrium conditions and will be the minimum amount of pumping necessary to dewater the quarry. From experience in surface mining it is considered that a normal advance dewatering system should be able to cope with the anticipated volumes of water needed to be pumped to gain drawdown. However, the total volume is not expected to be any higher than has generally been experienced in surface mining to date.

13. The hydrological model prepared by Aspinwalls agrees with the above. Figures produced for this are presented in Table II, from which it will be noted that the figure for total recharge is used as a more reliable guide to pumping capacity. A figure of 7 Mm^3/a is estimated as the maximum dewatering requirement which can exist for quarrying to any depth within the limestone series.

CHAPTER VI

RESEARCH WORK

GENERAL

1. A desk study of written material, maps and information provided by Foster Yeoman was made along with a literature survey of recent memos, maps, papers and theses in the geology of the Mendip area. A full bibliography is to be found at Appendix "A". No significant field investigation has been made in the immediate area of the quarry except for the work by Hussey (1984) and Vincent (1988). Hussey made a detailed geotechnical assessment of the north wall of the quarry and Vincent concentrated on the geology of the Beacon Hill Pericline.

2. The most important new finding, with significance to the geotechnical design of the quarry, was found during the literature survey which uncovered a paper by Williams and Chapman (1986) which further developed the theory of major thrust faulting in the area and suggested that the Cranmore Fault, forming the southern boundary of the quarry, was a thrust zone. The dissertation by Vincent also suggests a thrust zone to the east of Shute Farm.

3. It was the observation of these apparent thrusts in the field, allied to the results of this literature search, which dictated the urgent need to extend the examination to include the thrust faulting. The existence or non-existence of these thrust planes and their ramifications needed to be addressed with some urgency considering the potential extension of the quarry to depth. To this end Professor Williams visited the quarry in late March 1988 to study the potential problem. His findings have considerable relevance, particularly, for the north wall design, where thrust ramps will daylight at very unfavourable angles, in some cases in poor quality material.

STABILITY ANALYSIS

4. For any given slope, a full stability analysis needs to include the engineering parameters of the rock itself, the orientation of the discontinuities within it, the groundwater table height and the orientation of the high wall. The final high wall design, for the lateral extension to Bench C horizon, presented on Plate 10, has been assessed using the collated information, including principally the orientation of the discontinuities as presented on stereoplots, groundwater information and results of residual shear strength and internal friction angle values. This information has been sufficient to position the top of batter with a reasonable degree of certainty.

STEREOPLOTS AND HIGHWALL DESIGN

5. All the relevant information from the fieldwork, regarding the orientation of discontinuities is plotted on the stereonets, Plates 11 to 21 inclusive. Bedding planes, joints and fault planes are all included along with friction circles of 36° and 24°. This friction angle is an average taken from limestone data collated by Denby (1983) and also takes into account the work by Hussey (1984). The results of the laboratory analyses of the samples taken during this study give a mean coinciding with this value analysis. The slope face great circles on the stereoplots in the west wall are those for the quarry extension and not the present high wall.

9. Three samples were cut out by standard methods, carefully sealed and transported to the Mining Department laboratories of Nottingham University.

10. Four core samples were also selected and taken for testing. Two samples of AQ coring were taken from Shute Farm borehole 3 from a depth of 33.8 m (sample 4) and 34.7 m (sample 5). Sample 4 contained an inclined bedding plane with a 40° dip and sample 5 a similar feature but with red clay infilling. Both planes exhibited signs of movement.

TESTING

11. All samples were tested in the laboratory to obtain friction and cohesion values. The results are presented at Appendix "D". The values of cohesion and internal friction obtained are used for calculations of safe slopes in this Report. Sample testing on the fill material at different moisture contents was not carried out.

12. In the event, uniaxial compressive strength (UCS) values were obtained on four samples. These gave results in the range 33 to 89 MPa, moderate to medium strength rock. These results are compared with results from previous tests undertaken for Foster Yeoman, for quality assessment, in solid limestone beds showing results in the range generally of 59 to 98 MPa. One such sample of very hard, dense rock measured 187 MPa, but was very brittle, being only 9.4 MPa in tension (measured by Brazilian disc method).

ANALYSIS

13. All samples were prepared in accordance with International Society of Rock Mechanics (ISRM) Standards. The core samples were tested for Young's Modulus, Poisson's Ratio and UCS. These values are representative, but do not include the weakest material in the quarry or extension.

14. Shear stress was measured against displacement at different normal stresses. Values of shear strength and cohesion, at natural moisture contents were thus obtained. The fill material was similarly tested in isolation to obtain residual shear strength.

15. Inspection of the quarry and boreholes, however, and particularly the borehole in the extreme north, indicates that there is a considerable amount of weaker material which gives cause for concern. At some time in the future, further testing on this material is likely to be required. Such work is beyond the scope of the current study.

RESULTS

16. Angles of internal friction, with natural joint surfaces, were in the range 34° to 37°, typical of carboniferous limestone. The residual shear strength value of the fill material was governed by a friction angle of only 24°.

17. These results were applied to the computer analysed slope design.

18. The summary of the laboratory testing and results are presented at Appendix "D".

CHAPTER IX

FINAL DESIGN

OVERALL PARAMETERS

1. The lateral extension has been designed with a stand off from Downhead Road and occupied properties such that any subsequent quarrying, deeper than that currently proposed, can be accommodated safely with the face and bench profiles set out.

2. The top of batter or excavation limit is shown at surface on Plate 10 and superficial deposits and rock will be excavated within this line. The superficials will stand, when weathered, around the angle of repose of 35° to 40°. However, it is proposed to trim back through surficials of 1 in 3 (18.4°). This is suitable for tree planting and maintenance and, indeed, is the same as proposed for the inside of the amenity embankment. It also inhibits erosion due to run off.

3. A bench at rockhead will be maintained for both safety and retention of debris prior to the establishment of plant growth.

4. Below this, a face of variable height is proposed, the base of which will be at a bench level of 220 m in the south, 200 m in the central area and 180 m in the north, depending on the original ground level, and will warrant working in separate lifts of about 10 m.

5. Foster Yeoman has already indicated that the company is planning a stone excavation system involving the crusher standing on the present Bench B horizon (about 182 m) for the extension, then working successive benches downwards. Material from above will be broken, loaded and hauled to dump at face above Bench B, where it will be double handled to the crusher hopper.

6. This implies that the face excavations on the present Bench A (200 m horizon) do not have to be critically located and can, to some extent, suit the blasting system used.

7. As discussed previously, there are strong advantages to ripping the weathered material and possibly some of the more competent material. At the north end of the extension, however, the Bench A level is effectively at ground surface. The option exists, therefore, of ripping some of the material in the north. This would enable the face in this area to be trimmed at about 45° with limited bench widths left.

8. Advancing southwards it is most economical, with the crusher at the 180 m horizon (approximating to Bench B) to have successive advancing terraces at 10 m intervals, 200, 210 and 220 m, with a central ramp, using truck haul at the 200 m horizon dumping over the face for loaders to double handle at 180 m.

9. This permits the tractors to rip the final walls at about 45° to give a tidy final appearance, with 5 m benches at each 10 m vertical interval or a full 20 m high, 60° angle face with wider bench at the 200 m horizon which would maximise stone recovery. The overall highwall design angle is thus maintained.

CHAPTER IV

ADDITIONAL CONSIDERATIONS

THE AMENITY EMBANKMENT

1. Foster Yeoman also sought BMCL's opinion on one further item. This was the request by SCC to consider moving the crest of the bund, or amenity embankment, in towards the quarry, ie further from Downhead.

2. An important consideration is the geotechnical ramifications of constructing the bund anywhere other than proposed. The location proposed in the Planning Application is on land with limited head material, increasing in depth towards the inside of the bund. The bund height is limited, however, and the bund sits on the ridge crest.

3. Moving the bund closer to the existing workings requires building a much higher, and consequently heavier, embankment on sloping land of which the top 10 to 15 metres is soils and loam. This bund could well overload the material below, and presents the potential for a classic circular type of failure with a circle tangential to ground surface, rockhead or some weak band of material above it.

DEWATERING SCHEME

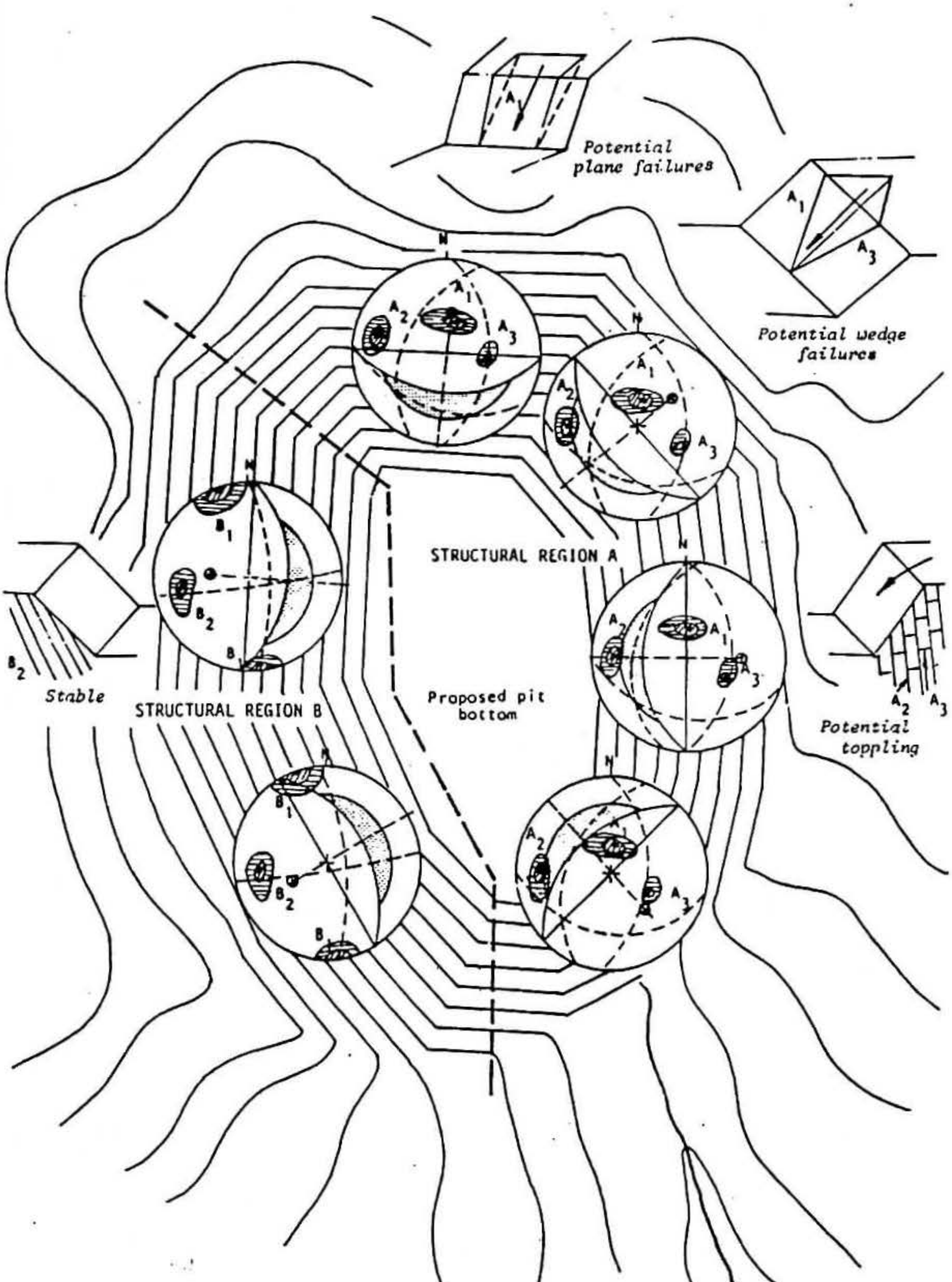
4. Another major consideration examined with Foster Yeoman and its hydrological consultants, Aspinwalls, at a further meeting on 5th January, was the work required and the programme and scheduling necessary to commission an advance dewatering scheme. To obtain a situation whereby the quarry is maintained in a dry state continually during quarrying is necessary, not only for operational reasons, but also to maintain stability of the designed walls. It has been agreed between Foster Yeoman, BMCL and Aspinwalls that the present sump system cannot continue indefinitely. It is disruptive to working and expensive.

5. Permitting water to enter the quarry, then pumping it out, results in polluted water which must be treated. Such volumes will increase when working below the water table. Advance dewatering from boreholes will avoid this problem.

6. To produce an effective scheme, including the design of augmentation water facilities, requires a great deal of work. In brief, this includes test drilling, testing, further drilling, analysis, test pumping, design of make up water to other sources, design of wells, design of reservoir, planning application and consent, tender, award and construction of reservoir contract and water filling. The programme requires a minimum of seven years' work, on Aspinwalls' evaluation, with nothing causing any delay. Based on experience, a more realistic programme is 10 to 12 years.

7. The main implication of the above is that any lateral extension must provide a minimum of seven, but preferably ten years of workable reserves, before resorting to quarrying below the water table. Consequently the proposed alternative tabled by SCC does not provide this. The second option, proposed by Foster Yeoman, similarly provides insufficient reserves, although the situation is better.

8. If augmentation is obtained from another source ie not requiring the construction of a new reservoir, the time required could reduce. This is unknown, however, at present.



Presentation of structural geology information and preliminary evaluation of slope stability of a proposed open pit mine.

ZONE ; **central**
WALL ; **west**

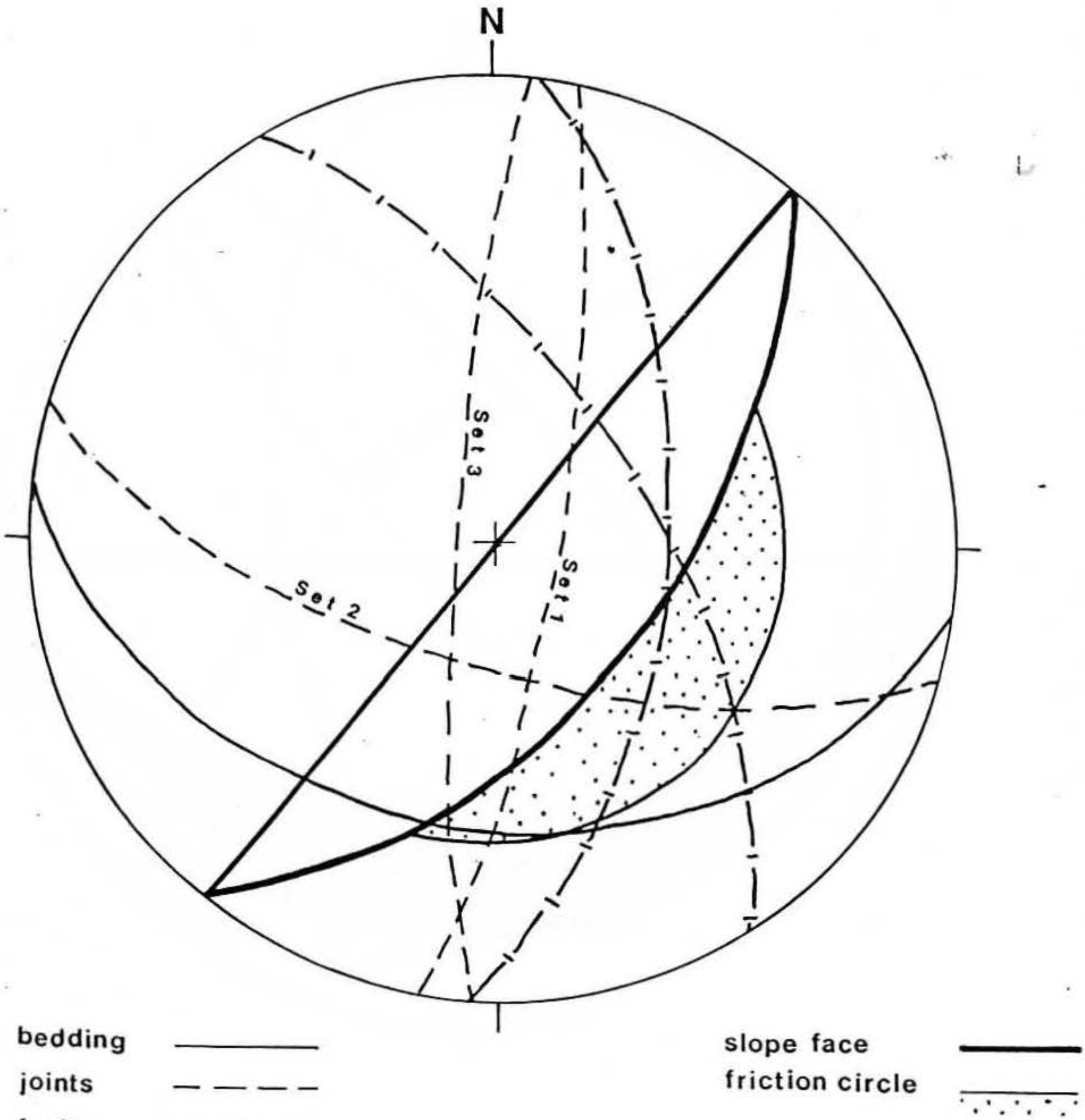


Figure 7 **Torr Quarry ~ Foster Yeoman**

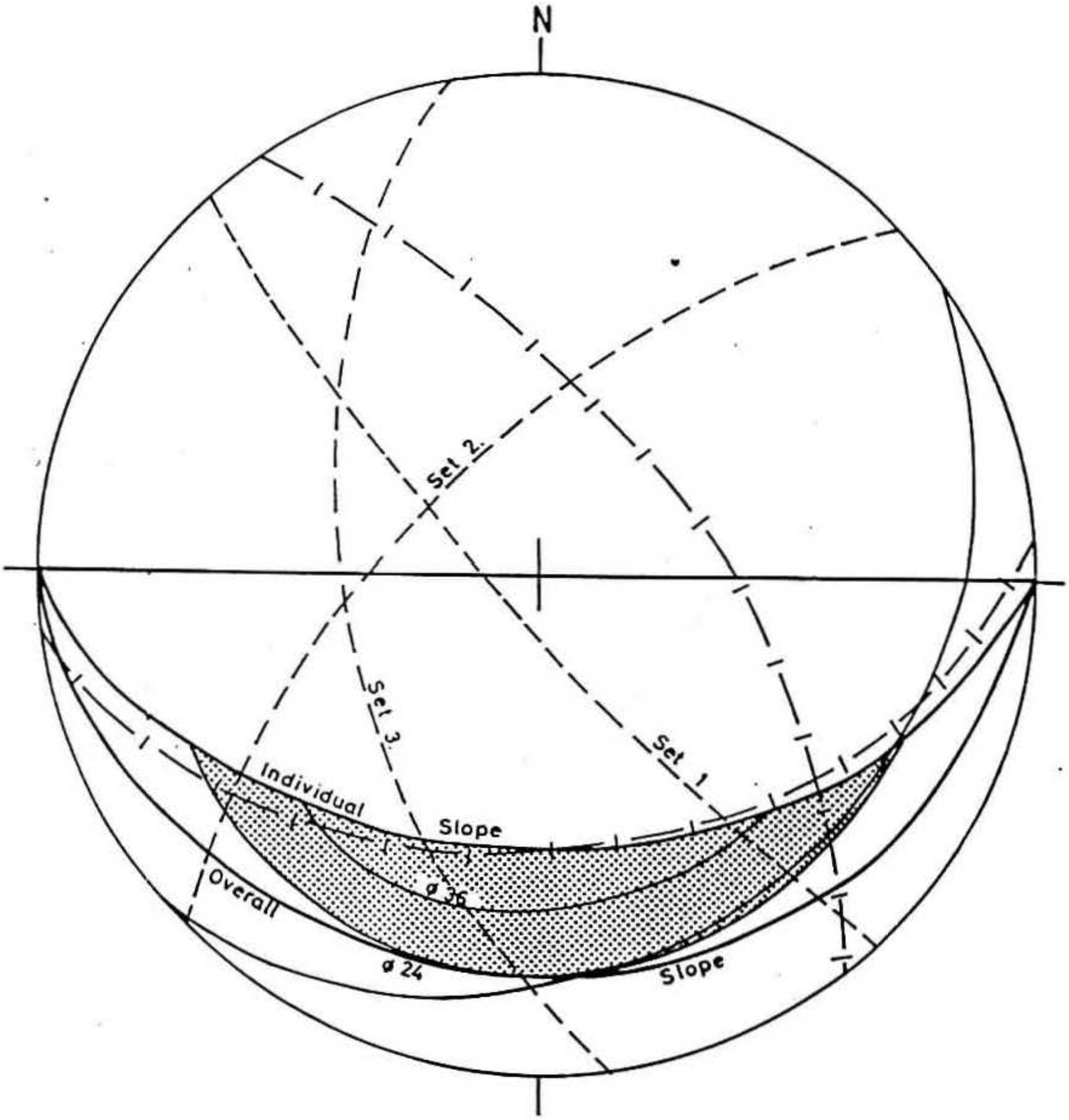
Equatorial equal-area stereonet

PROJECT

TITLE

P J Norton Associates

DRAWING Nº



Bedding ————

Joints - - - - - -

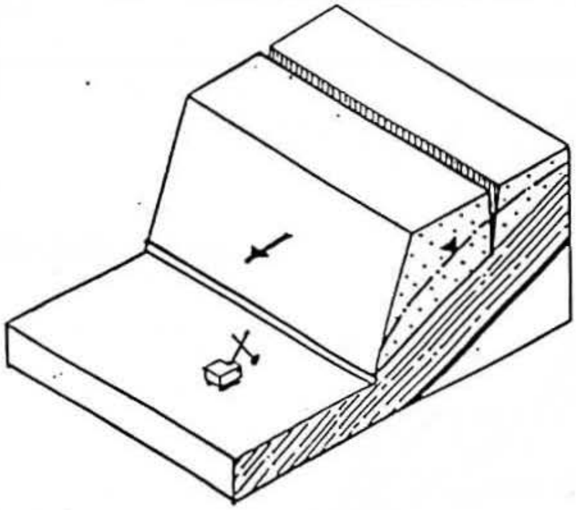
Faults —|—|—|—

Slope face ————

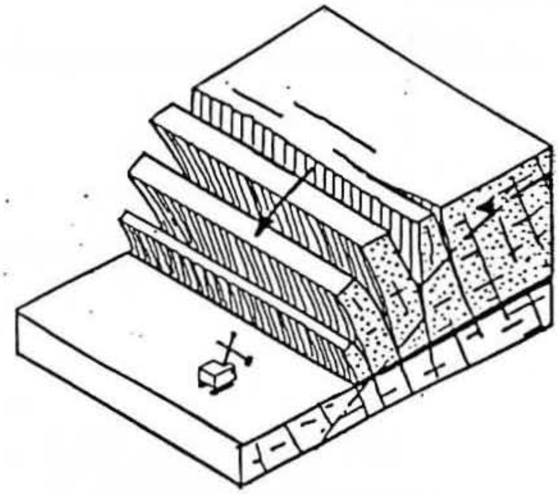
Friction circle

PROJECT
Slope Stability Study - Foster Yeoman

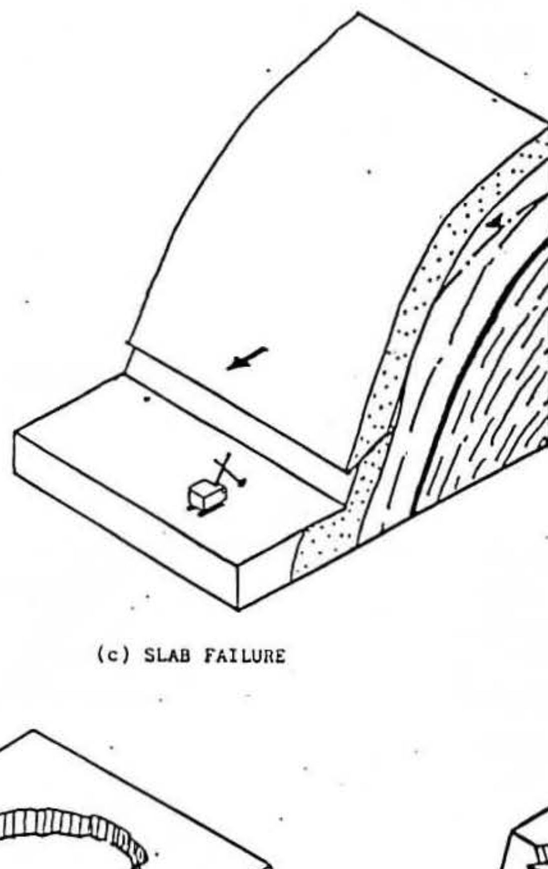
TITLE
ZONE: North WALL: North (1)



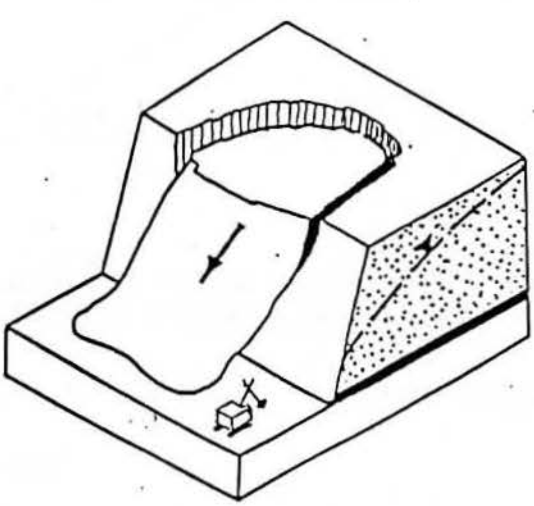
(a) PLANE FAILURE



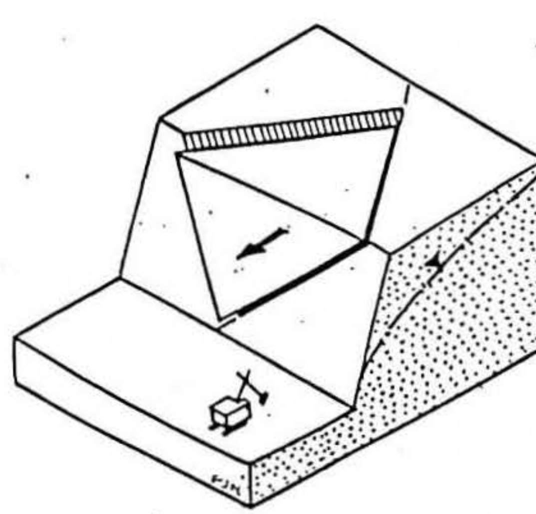
(b) TOPPLING FAILURE



(c) SLAB FAILURE



(d) CIRCULAR FAILURE



(e) WEDGE FAILURE

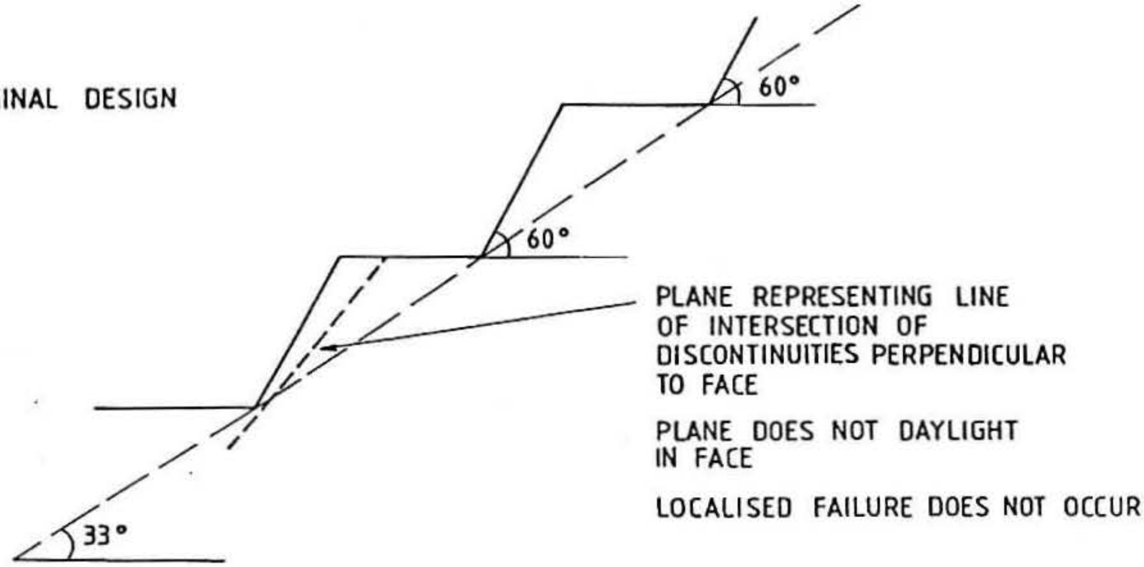
PROJECT

TITLE

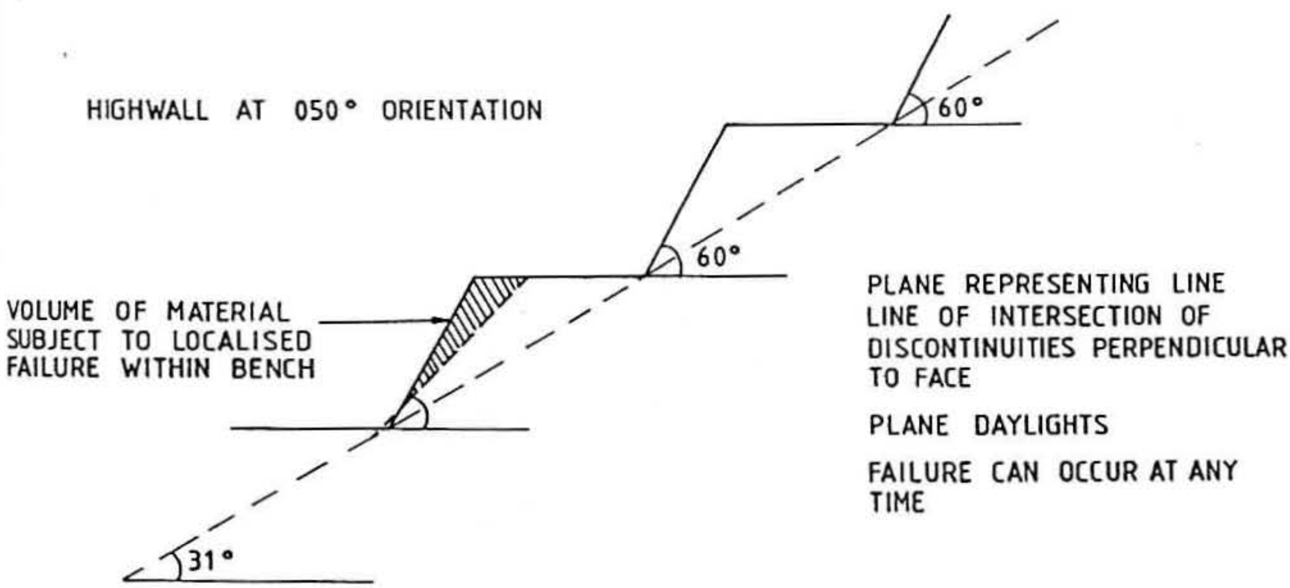
P J Norton Associates

DRAWING Nº

ORIGINAL DESIGN



HIGHWALL AT 050° ORIENTATION



THE POTENTIAL LOCALISED WEDGE FAILURE PROGRESSIVELY INCREASES AS THE FACE ORIENTATION INCREASES AND BECOMES MORE PARALLEL TO THE STRIKE OF THE BEDS.

WHEN PARALLEL, OR NEARLY SO, PLANE FAILURE WILL PREDOMINATE.

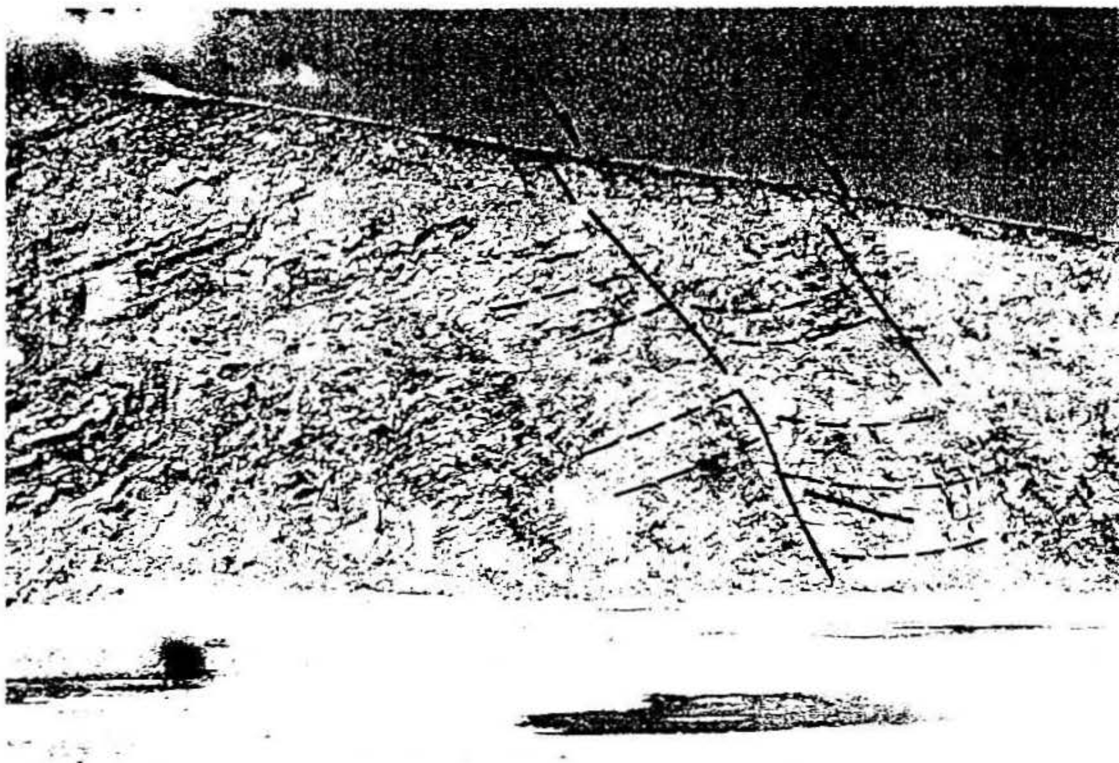
SCALE 1:1000

OJECT EVALUATION OF OPTIONS TORR WORKS QUARRY

TLE INDIVIDUAL SLOPE FAILURES

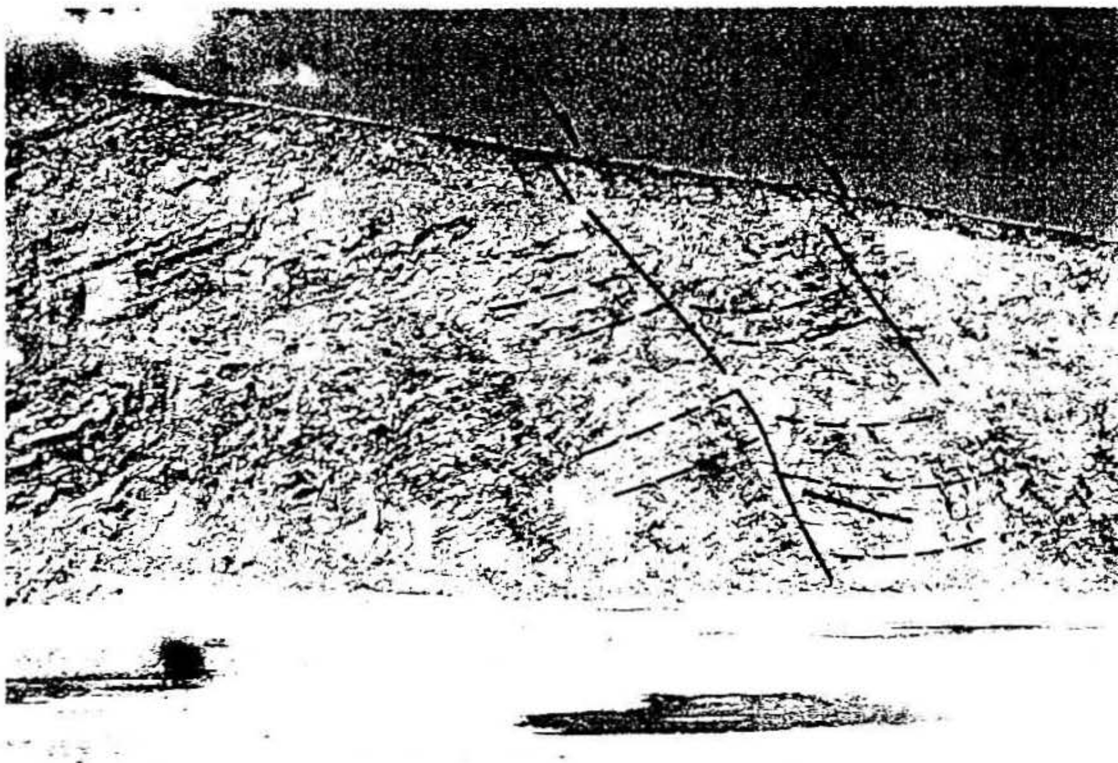
P J Norton Associates

DRAWING Nº



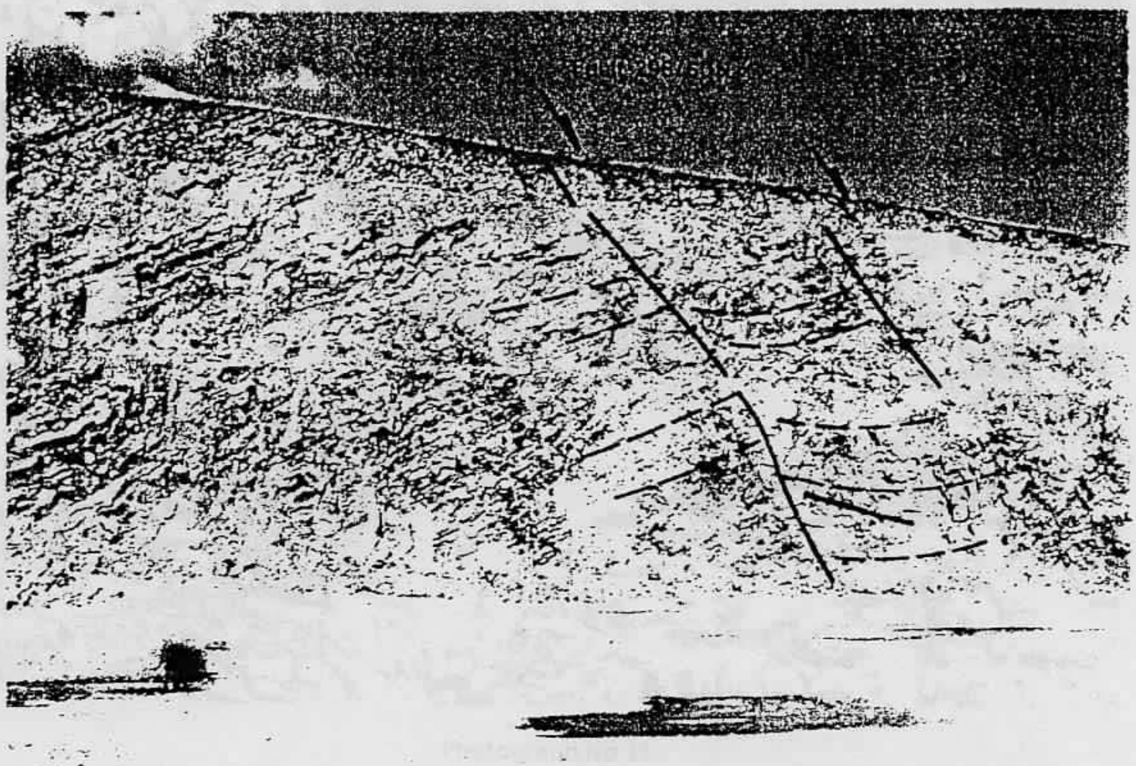
Photograph No 7
Benches A, B and C, W wall. Note the faults forming boundary between the Central and N zone
Hanging Wall Drag Fold

Photograph No 8
Bench B, N zone/W wall. Toppling failure



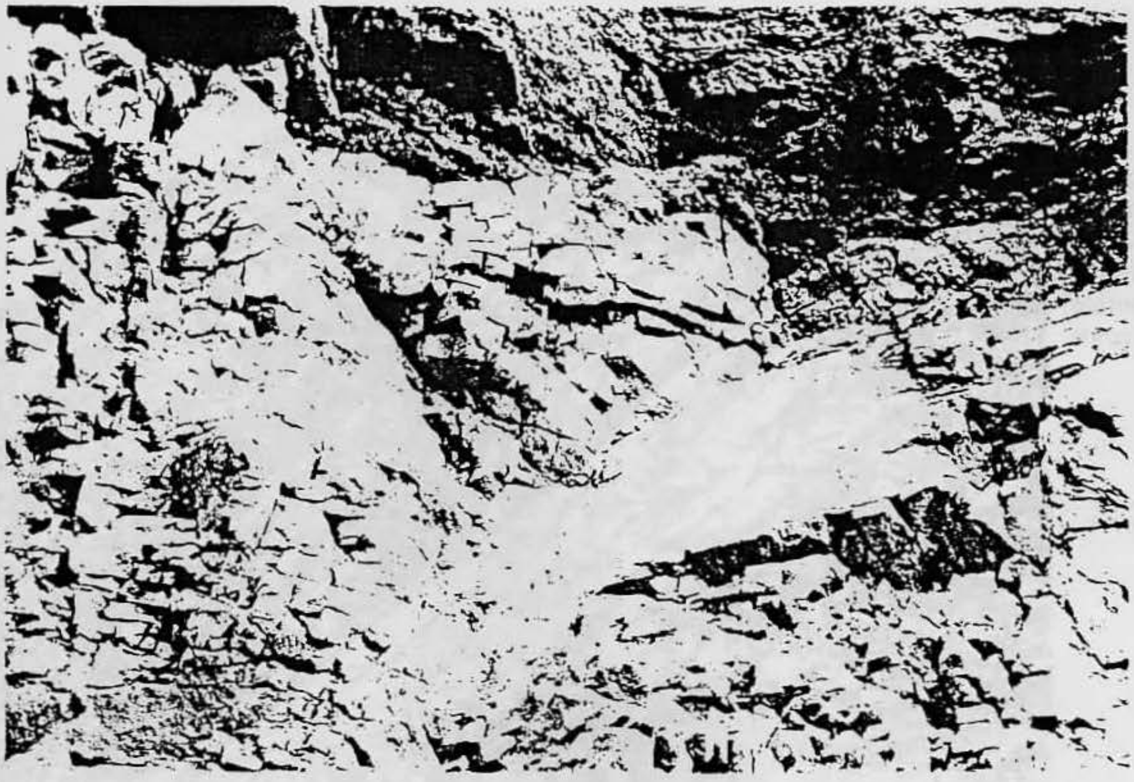
Photograph No 7
Benches A, B and C, W wall. Note the faults forming boundary between the Central and N zone
Hanging Wall Drag Fold

Photograph No 8
Bench B, N zone/W wall. Toppling failure



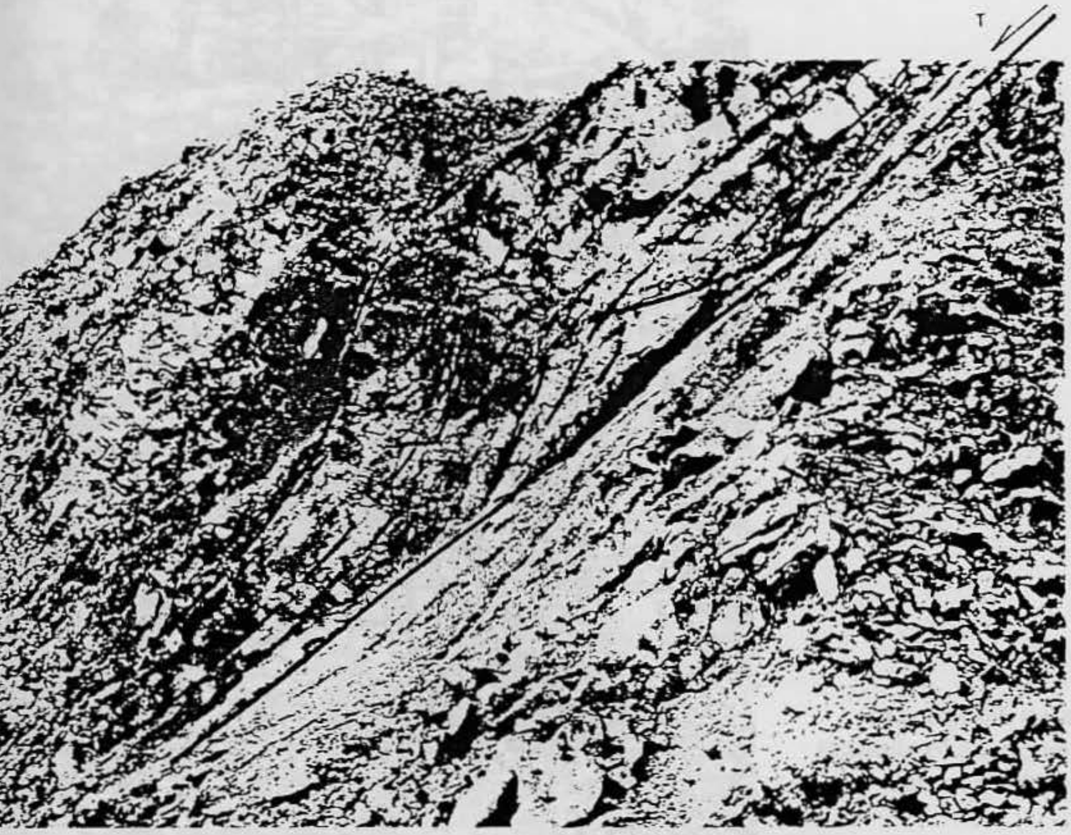
Photograph No 7
Benches A, B and C, W wall. Note the faults forming boundary between the Central and N zone
Hanging Wall Drag Fold

Photograph No 8
Bench B, N zone/W wall. Toppling failure



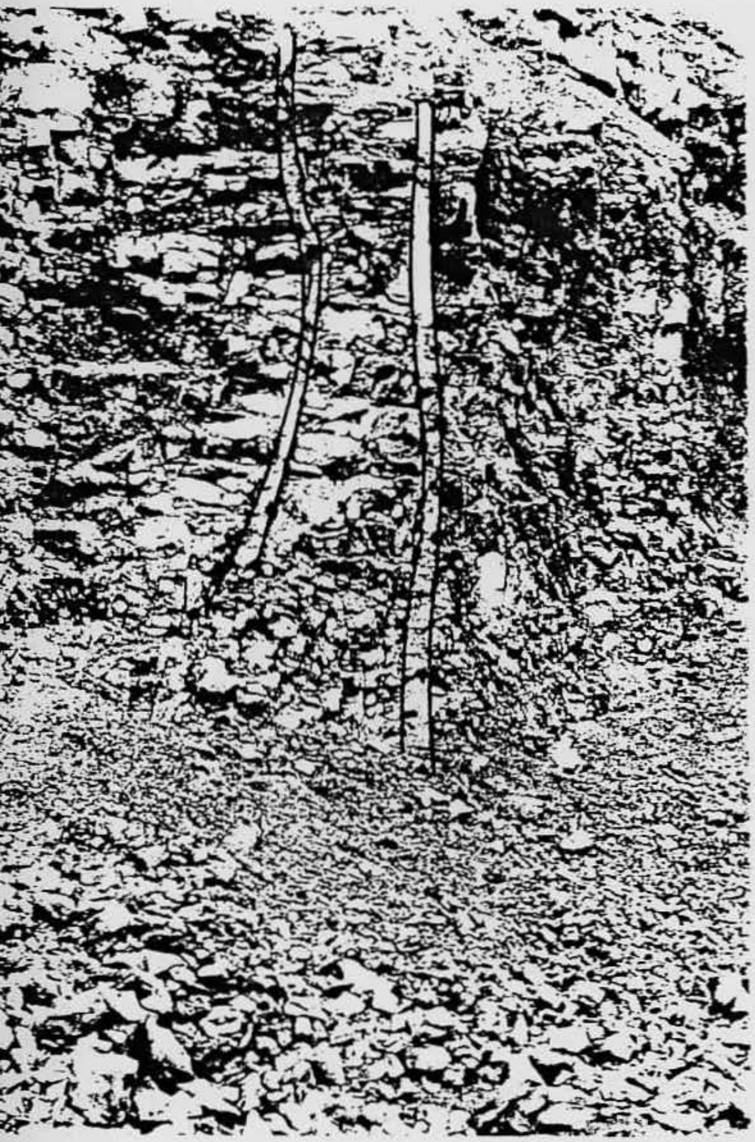
Photograph No 11
Bench B, N zone/E wall. Wedge failure

Photograph No 12
Bench B, N zone/E wall.Drag
features in fault zone



Photograph No 27
Backthrust related folding above thrust plane

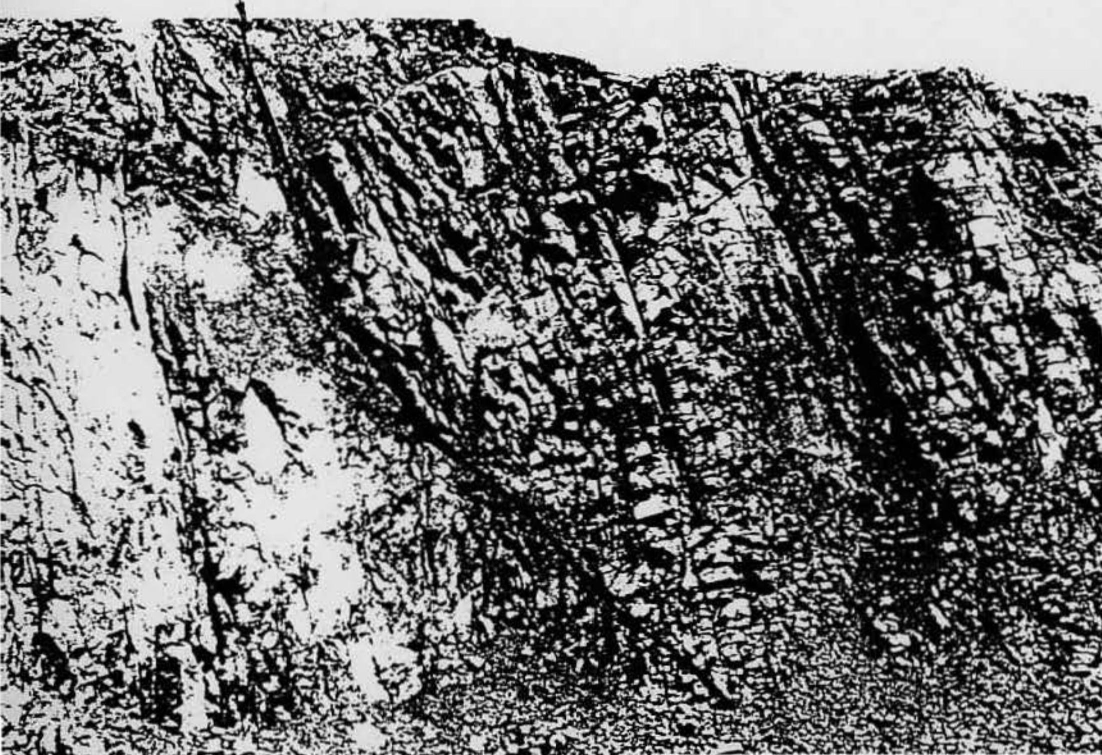
Photograph No 28
Bench B, N zone W wall



Veins trending
N - S

Photograph No 31
Example of dilational veins.
Calcite infilling.

Fault 320/64



Dilational
Joints

Photograph
No 32
Shear
fractures at
high angle
to bedding