

**Golder Associates Ltd.**

2390 Argentia Road  
Mississauga, Ontario, Canada L5N 5Z7  
Telephone: (905) 567-4444  
Fax: (905) 567-6561



**REPORT ON**

**ROCKFALL HAZARD ASSESSMENT  
HIGHWAY 6 WIDENING  
BETWEEN HIGHWAYS 403 AND 5  
G.W.P. 19-95-00**

Submitted to:

URS Canada Inc.  
75 Commerce Valley East Drive  
Thornhill, Ontario  
L3T 7N9

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## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) was retained by URS Canada Inc. (URS) to provide geotechnical engineering services as part of the TPM Detail Design for the reconstruction of Highway 6 from Highway 403 to Highway 5 (W.P. 19-95-00). This report presents the results of the rock hazard assessment, which was carried out to determine the stability conditions of the existing rock cuts as well as the likely stability concerns for the new rock cuts to be created as part of the road widening.

The work carried out included detailed geotechnical mapping of the existing rock cuts and a stability assessment based on the field data collected. Recommendations for remedial rock stabilization work are also provided for the existing rock cuts on both sides of Highway 6.

Drawings showing the configurations of both the existing and new Highway 6 geometries for the contract area were provided to Golder by URS. At the time of the investigation, the chainages for the new alignment had been staked out by surveyors in the area of concern. The rock cuts are shown in plan on Figure 1.

## **2.0 INVESTIGATION PROCEDURES**

The areas under investigation were photographed early in the field investigation and these photographs were used for recording the data from the detailed geotechnical mapping of the rock cuts. For each rock cut, the orientations (dip/dip direction) of the major discontinuities, including representative joint sets, were measured and the characteristics of the various discontinuities were noted including the persistence, aperture, shape, roughness and infilling of the joints as well as any groundwater seepage. The rock cuts were also inspected in detail and any potential failure mechanisms or evidence of past failures were noted in order to assess their current stability condition.

The field assessment of the exposed rock cut faces on the east and west sides of Highway 6 between Chainages 12+375 and 12+675 was carried out on November 7 and 8, 2000 by members of Golder's rock engineering staff. The rock mass characterization, which comprised detailed discontinuity mapping and geotechnical descriptions of the exposed rock, was carried out on foot from the toe of the existing rock cuts along both sides of Highway 6. An inspection of the crest areas of the rock cuts was also carried out to collect additional geotechnical data and to check for evidence of instabilities (i.e. open joints or tension cracks).



### **3.0 GENERAL SITE GEOLOGY AND STRATIGRAPHY**

#### **3.1 Site Geology**

The site consists of both Silurian and Ordovician sedimentary bedrock which is comprised primarily of dolostones, limestones, sandstones and shales. At the site location, Highway 6 traverses the Niagara Escarpment, which is the main physiological feature in the area. Where the highway crosses the escarpment; vertical rock cuts have been constructed on either side of the roadway up to approximately 15 m high.

#### **3.2 Site Stratigraphy**

The stratigraphy of the upper portion of the Niagara Escarpment in the vicinity of Highway 6 comprises the lower members of the Lockport Formation, the Rochester, Irondequoit, Reynales, Thorold, Grimsby and the Cabot Head Formations. The lower members of the Lockport Formation encountered include the base of the Goat Island Member as well as the Gasport Member.

A brief description of each of these stratigraphic units (from the top downwards) is provided in the following sections.

##### **3.2.1 Lockport Formation**

###### **Goat Island Member**

The Goat Island Member consists of 11.0 m to 12.5 m of dolostone that is comprised of three distinct units. Only the lower 2 m of the basal unit (Unit 1) is encountered on site. It is a grey to buff, fine to medium grained, thinly bedded dolostone, which is medium to closely jointed with abundant whitish chert nodules.

###### **Gasport Member**

The Gasport Member is a light to medium creamy grey, medium to coarse grained, partly crystalline, pitted, medium to thickly bedded, massive textured, moderately jointed, dolostone. This member is approximately 3.5 m thick.

##### **3.2.2 Rochester Formation**

The Rochester Formation is comprised of medium grey, fossiliferous, shaley dolostone and soft fissile shale. The upper half of the formation is largely shaley dolostone while the lower half is shale. This 2 m thick, formation forms a regional aquitard and controls ground water movement such that springs are common along the upper contact of the shale where it outcrops on the Escarpment and road cutting faces.

### **3.2.3 Irondequit Formation**

The Irondequit Formation, which is about 1.5 m thick, consists of a light to medium grey, medium grained, crystalline, medium to thickly bedded, massive textured, medium jointed, crinoidal limestone and dolomitic limestone.

### **3.2.4 Reynales Formation**

The Reynales Formation is comprised of a light to medium greenish grey, fine to medium grained, thin to medium bedded, closely jointed, argillaceous dolostone, with thin interbeds of greenish grey shales. The formation is about 2 m thick at this location.

### **3.2.5 Thorold Formation**

The Thorold Formation consists of a 3 m thick, interbedded sequence of medium to dark green fissile shale and light grey, fine to medium grained, thin to medium bedded sandstone and siltstone.

### **3.2.6 Grimsby Formation**

The Grimsby Formation is comprised of a dark reddish brown, thinly bedded to laminated mudstone and fissile shale with occasional interbedded siltstone. The formation is about 3 m thick at this location.

### **3.2.7 Cabot Head Formation**

The Cabot Head Formation is predominately comprised of a medium grey, fissile shale with occasional thin interbeds of siltstone and dolostone. It varies in thickness between approximately 16 m to 17 m beneath the Dundas-Hamilton area. The upper contact is transitional, marked by the transition from red Grimsby shale to grey Cabot Head shale.

## 4.0 ASSESSMENT OF ROCK HAZARDS

### 4.1 Structural Mapping

Structural mapping was carried out along the exposed rock cut faces on the east and west sides of Highway 6 within the general limits of the proposed highway widening. A total of 148 discontinuities were mapped. Inspection of the stereographic projections, shown on Figure 2, suggests that four discontinuity sets are present, comprising three sub-vertical joint sets (J1 to J3) and the near horizontal bedding (J4). Each of the discontinuity sets are annotated on the contour stereographic plots and rosette diagrams on Figure 2. The dominant set (J1) accounts for more than 43 per cent of all the discontinuities measured. The J2 and J3 sets account for 18 and 29 per cent of all the discontinuities measured, respectively. The average strike orientation of the J1, J2 and J3 sets is to the south, north-west and west, respectively. The J3 set has a WSW striking sub-set (comprising 7 per cent of all the discontinuities measured) which has been labelled the J3a set.

Joint sets J1, J2 and J3 are all near-vertical and the bedding (J4) dips slightly (approximately 1° on a local scale) towards the northeast, but is essentially flat-lying. [Note that all measurements are with respect to the Magnetic North (MN); for True North (TN) readings add 10° to the MN values.] The physical attributes of the discontinuity sets are summarized in the table below:

<i>Discontinuity Set</i>	<i>Average Dip/Dip Direction</i>	<i>Spacing (m)</i>	<i>Roughness</i>	<i>Filling</i>	<i>Aperture (mm)</i>	<i>Continuity (m)</i>
J1	89/090	0.5-6.0	Smooth-Rough Planar	Generally clean, minor calcite	Tight	2.0->10.0
J2	89/238	0.5-4.0	Smooth-Rough Planar	Generally clean, minor calcite	Tight	1.0-10.0
J3	89/186	0.5-8.0	Smooth-Rough Planar	Generally clean, minor calcite	Tight	1.0-4.0
J3a	89/150	0.5-8.0	Smooth-Rough Planar	Generally clean, minor calcite	Tight	1.0-4.0
Bedding	Flat bedded	0.01-0.4	Smooth Planar	Generally clean, minor calcite	Tight	Continuous over large distances

The rock mass conditions on either side of Highway 6 are shown in Plates 1 and 2. Common lithostratigraphic units can be identified in both road cuts as shown on the Plates. Both cuts exhibit slight blast damage (likely from original construction) and extensive weathering and ravelling due to frost action.

At the time of the inspection some minor seepage was noted, primarily along the upper contact of the Rochester Shale as shown on Plates 1 and 2. It should, however, be noted that groundwater levels are expected to fluctuate seasonally and are expected to be higher during wet periods of the year.

## 4.2 Stability Assessment

Failures in the exposed rock cuts will generally be structurally controlled, kinematic type failures (as opposed to larger scale failures through intact rock). These types of failures occur as the result of movement along pre-existing geological discontinuities (i.e. joint or fault planes). The three basic mechanisms of structurally controlled failure in rock slopes are plane failures, wedge failures, and toppling failures.

A plane failure may occur when a geologic discontinuity dips out of a rock slope at an angle that is steeper than the effective angle of friction and shallower than the inclination of the slope (i.e. it daylights along the cut face). Plane failures will generally only develop to a significant extent if the strike of the geologic discontinuity is within  $\pm 20^\circ$  of the azimuth of the rock slope.

Wedge failures may occur when two or more geological discontinuities intersect to form an unstable wedge. In order for a wedge to fail, the line of intersection of the wedge must dip out of the slope at an inclination that is shallower than the inclination of the slope, but steeper than the effective angle of friction along the discontinuities. Wedge failures will only develop to a significant extent if the azimuth of the line of intersection is within  $\pm 45^\circ$  of the dip direction of the slope face.

Toppling failures may develop when a rock mass contains multiple, steeply dipping continuous structures, such as bedding or foliation planes, that strike nearly parallel to the strike of the face of the rock slope. Toppling failure will generally only develop when the strike of the structures is within  $\pm 20^\circ$  of the azimuth of the slope face.

All structurally controlled failure modes are aggravated by water pressures within the slope and toppling failures are particularly sensitive to water pressure. The magnitude and frequency of structurally controlled failures are directly related to the frequency, spacing and continuity of the structures along which sliding can occur.

In terms of kinematic stability, wedge and planar type failures are unlikely along both the east and west rock cuts at Highway 6 due to the typically sub-vertical joint sets (refer to Figure 3). During excavation of the new road cuts there is a slight possibility of toppling failure, since the J2 set is nearly parallel to the orientation of the cut. However, it is likely that most unstable blocks would be dislodged during blasting and subsequent scaling. The prominent J1 and J2 sets may have an adverse affect on overbreak during blasting wherever they are present. Stability of the ultimate rock slopes will be mostly affected by the quality of the controlled blasting.

For the existing rock cuts, and over time for the proposed cuts, the most likely type of failure will be surface ravelling as a result of ongoing weathering processes. The most significant of these processes include freeze-thaw cycles in the winter months resulting in ice jacking in the shale and

dolostone/limestone units and wetting-drying cycles in the shale units. The result will be ravelling of small blocks, generally less than  $0.5 \text{ m}^3$  in size, which will fall toward the roadway. The provision of an adequate catchment area (clear zone and catch ditch) would generally be sufficient in mitigating the risk of rock reaching the travelled portion of the roadway for the new rock cuts while some scaling would be required for the cut faces which are to be left as is.

Some minor undercutting in the Rochester shale within the existing rock cuts was noted during the field inspection. To date, this has not developed into a major stability problem for the overlying units due to the very limited extent (depth) of the undercutting which is estimated to be less than 0.5 m.

It should also be noted that some open joints were identified along the crest of the west rock cut during the field inspection (refer to Plates 3 and 4). Further opening of these joints through blasting or ice-jacking could result in toppling failure.

## **5.0 ROCKFALL HAZARD REMEDIATION**

### **5.1 General**

This section of the report provides recommendations on the remediation of rockfall hazards, based on interpretation of the factual information obtained during the site investigation. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction method and scheduling.

### **5.2 New Rock Cut Faces in Widened Areas**

Inspection of all new rock cut faces by qualified geotechnical personnel immediately after blasting should be carried out in order to assess where scaling/loosened rock removal should be carried out. All loose, unstable rock should be removed from the cut faces before access to the toe area of the slope is permitted.

Inspection of the rock cut face by qualified geotechnical personnel immediately after blasting should also be carried out in order to determine whether any rock bolting (provisional item only) may be required. The rock bolts, if required, should be 25 mm diameter, galvanized, fully grouted deformed bars, generally 3 m in length; however, the length should suit the specific circumstances.

### **5.3 Remedial Measures for Existing Cut Faces**

The condition of the existing rock cuts and the recommended remedial works are shown on Plates 1 and 2. As shown on these plates, scaling of loose, weathered rock from the face of the existing cuts is required in the following areas (which are located south of the cut widening area), in order to minimize the risk of rock ravelling and rolling or bouncing and eventually reaching the roadway, as well as to reduce ongoing maintenance costs associated with clean-out of the ditches/catchment areas.

- South of Station 12+530 on the west side of Highway 6; and
- South of Station 12+500 on the east side of Highway 6.


The larger toppling blocks of rock located near the crest of the west rock cut (refer to Plates 2 to 4) should also be removed using a backhoe, possibly requiring a hoe-ram. Access to the crest may be difficult depending on the equipment used and therefore this work may require temporary ramps constructed at the toe of the slope using blast rock.

It is recommended that all loose, unstable rock be removed from the cut faces before access to the toe area is permitted.

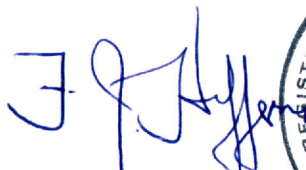
The rock scaling shown on Plates 1 and 2 has been divided into two broad types (in general agreement with existing MTO Special Provisions): heavy mechanical scaling and light to moderate hand scaling. Heavy mechanical scaling would normally require the use of a backhoe bucket and in some cases a large hoe-ram to remove larger blocks near the crest. Light hand scaling, as the name implies, is generally best carried out from a crane supported platform using hand tools (hand scaling bars). For the scaling shown on Plates 1 and 2, it is estimated that there would be approximately 45 hours of heavy scaling and about 25 hours of light scaling required.

These scaling categories have been assigned based upon the visual inspection of the existing rock faces. The loosening effect of physical weathering is expected to be less than 1.0 m in the areas designated as requiring heavy mechanical scaling, and less than 0.5 m in areas requiring light to moderate hand scaling. It should however be noted that due to the blocky nature of the rock mass, that over-scaling (particularly by mechanical methods) is a concern. With this in mind, it is recommended that the scaling be directed and supervised by qualified geotechnical personnel.

**GOLDER ASSOCIATES LTD.**

  
Mark J. Telesnicki, P.Eng.  
Associate



  
Fintan J. Heffernan, P.Eng.  
Designated MTO Contact



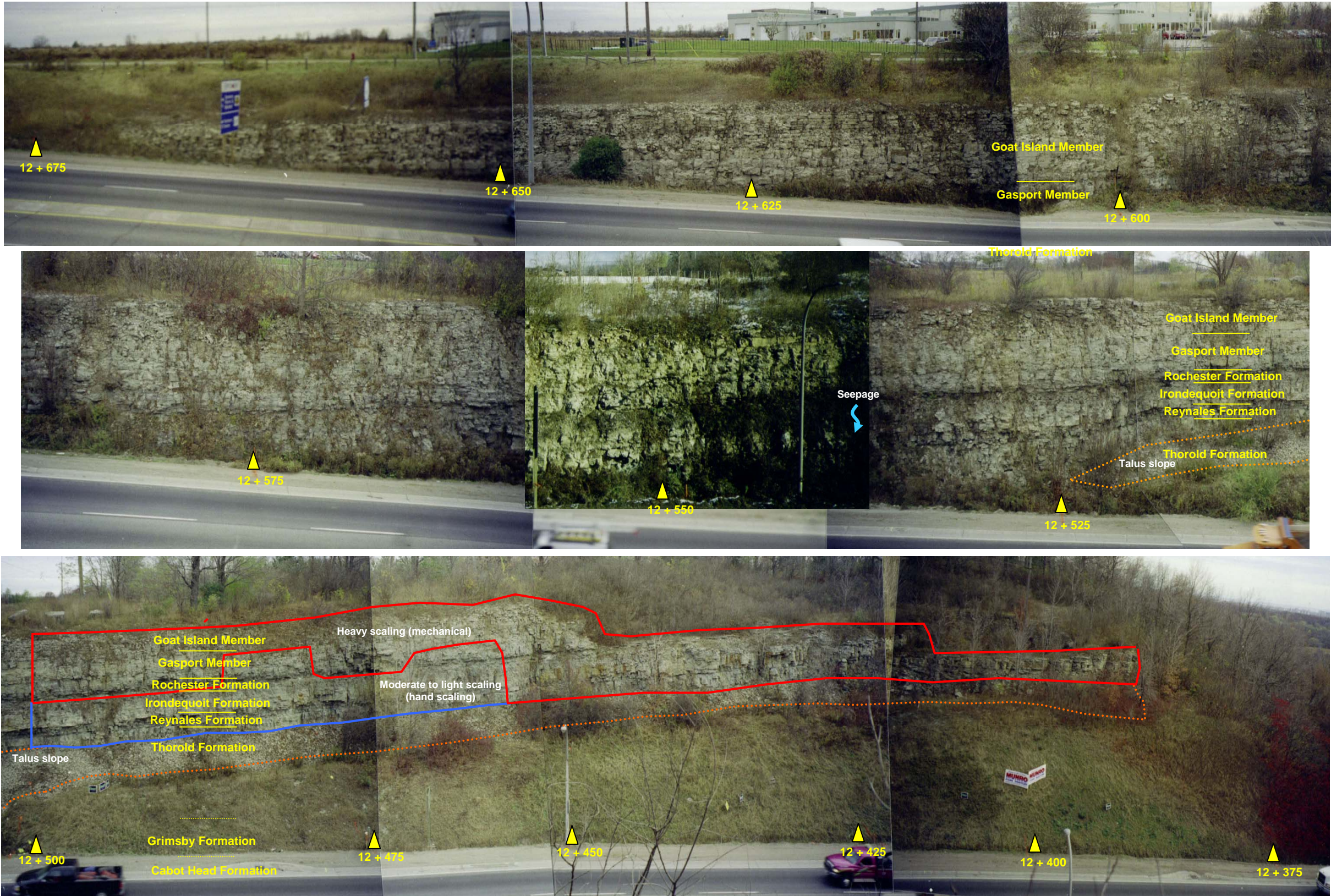
PdG/KC/LCC/MJT/FJH/pdg/kc

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EAST ROCK CUT - HIGHWAY 6  
STATION 12+375 to 12+675

PLATE 1



Date: June 2005  
Project: 001-1141F

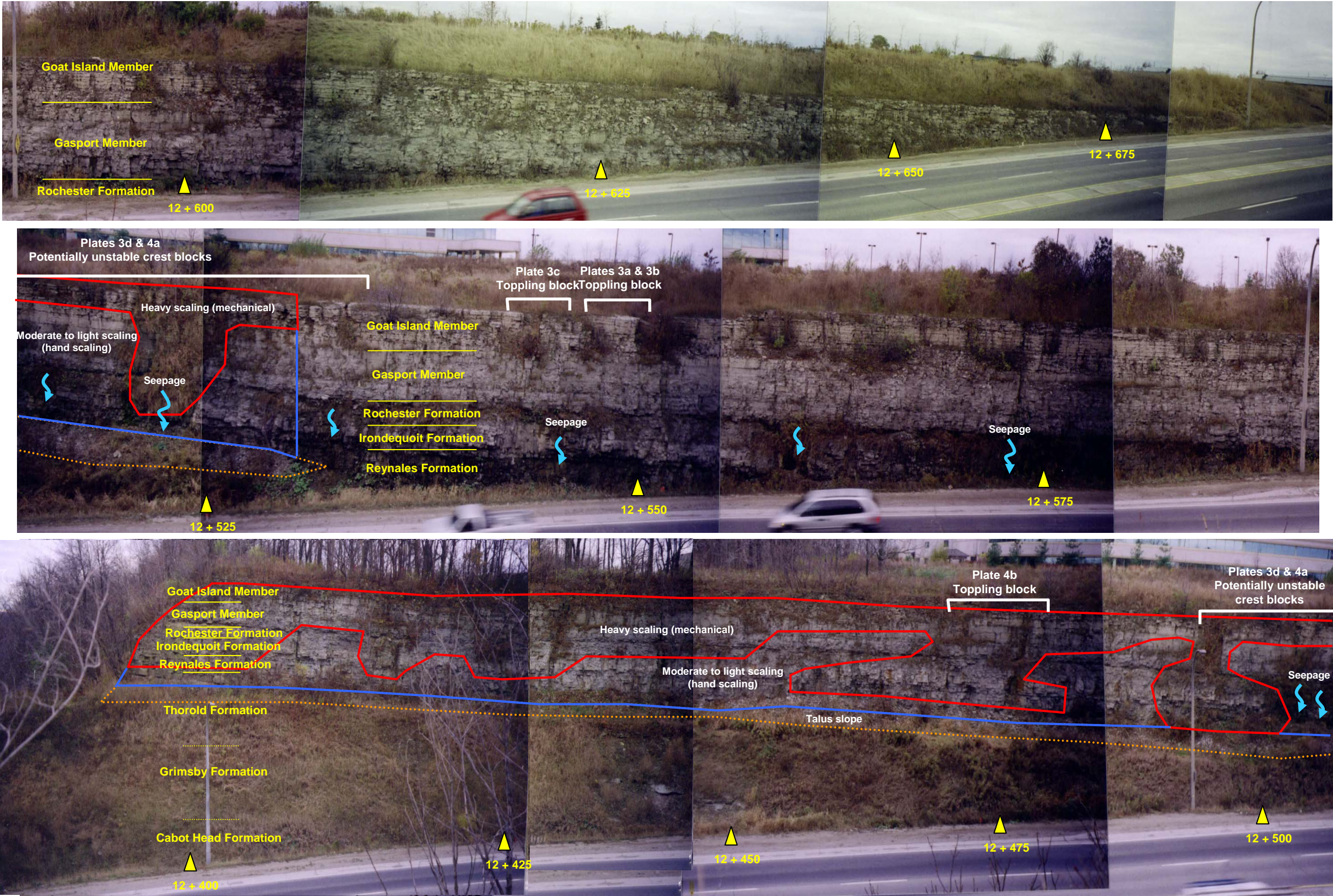
Golder  
Associates

Drawn: KJC  
Chkd: MT



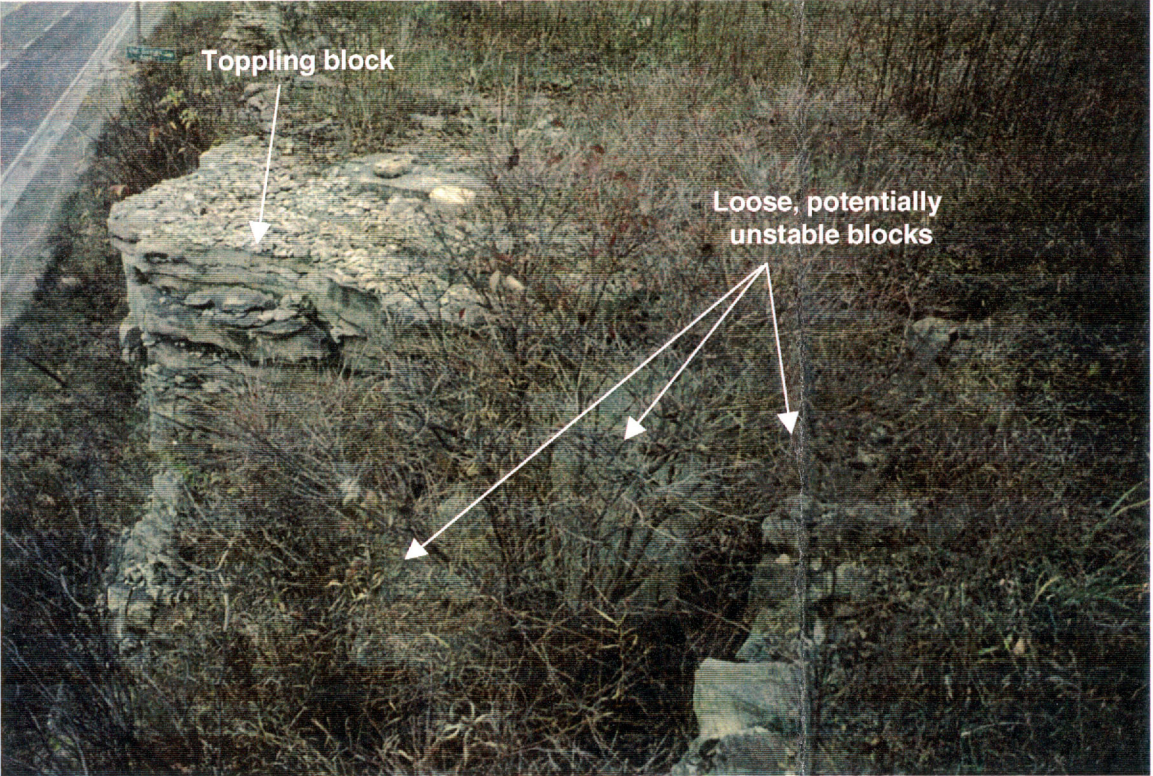
WEST ROCK SLOPE - HIGHWAY 6  
STATION 12+375 TO 12+675

PLATE 2

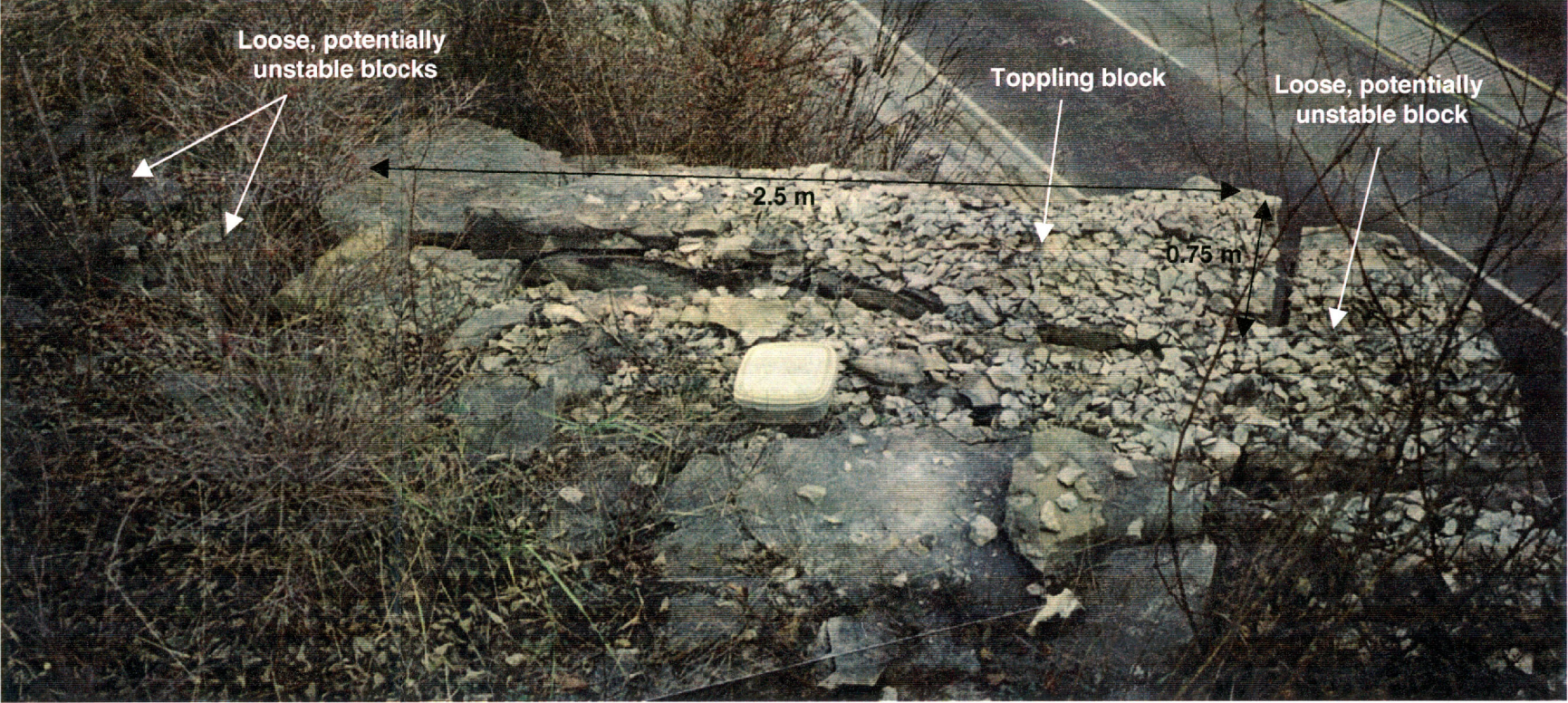




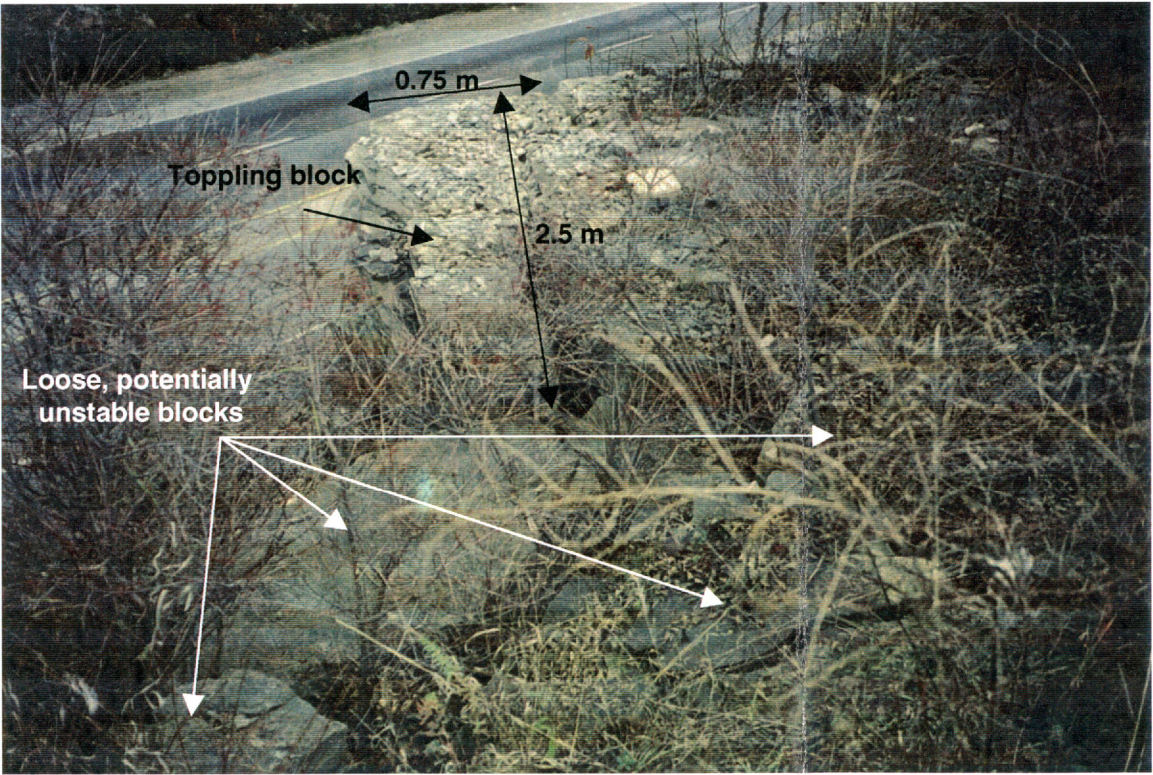
3a) Potential toppling block (Approx. CH 12+550)



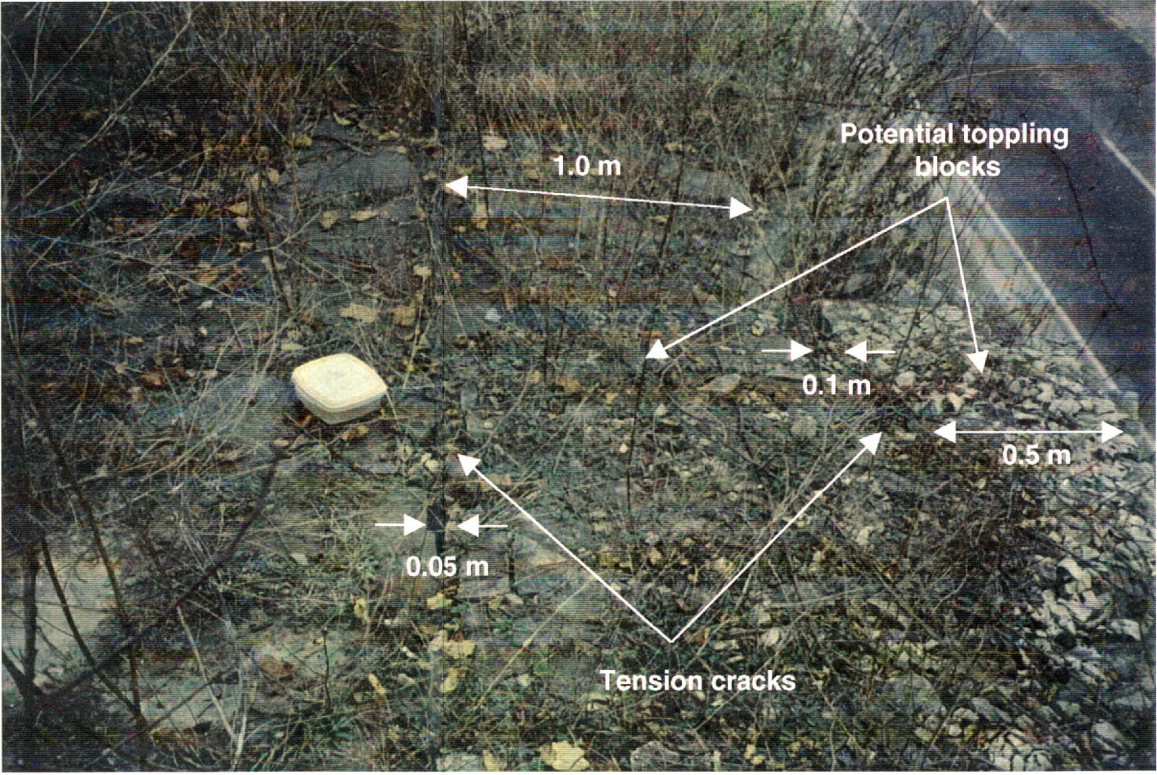
3b) Potential toppling block (Approx. CH 12+550)



3c) Potential toppling block (Approx. CH 12+550)



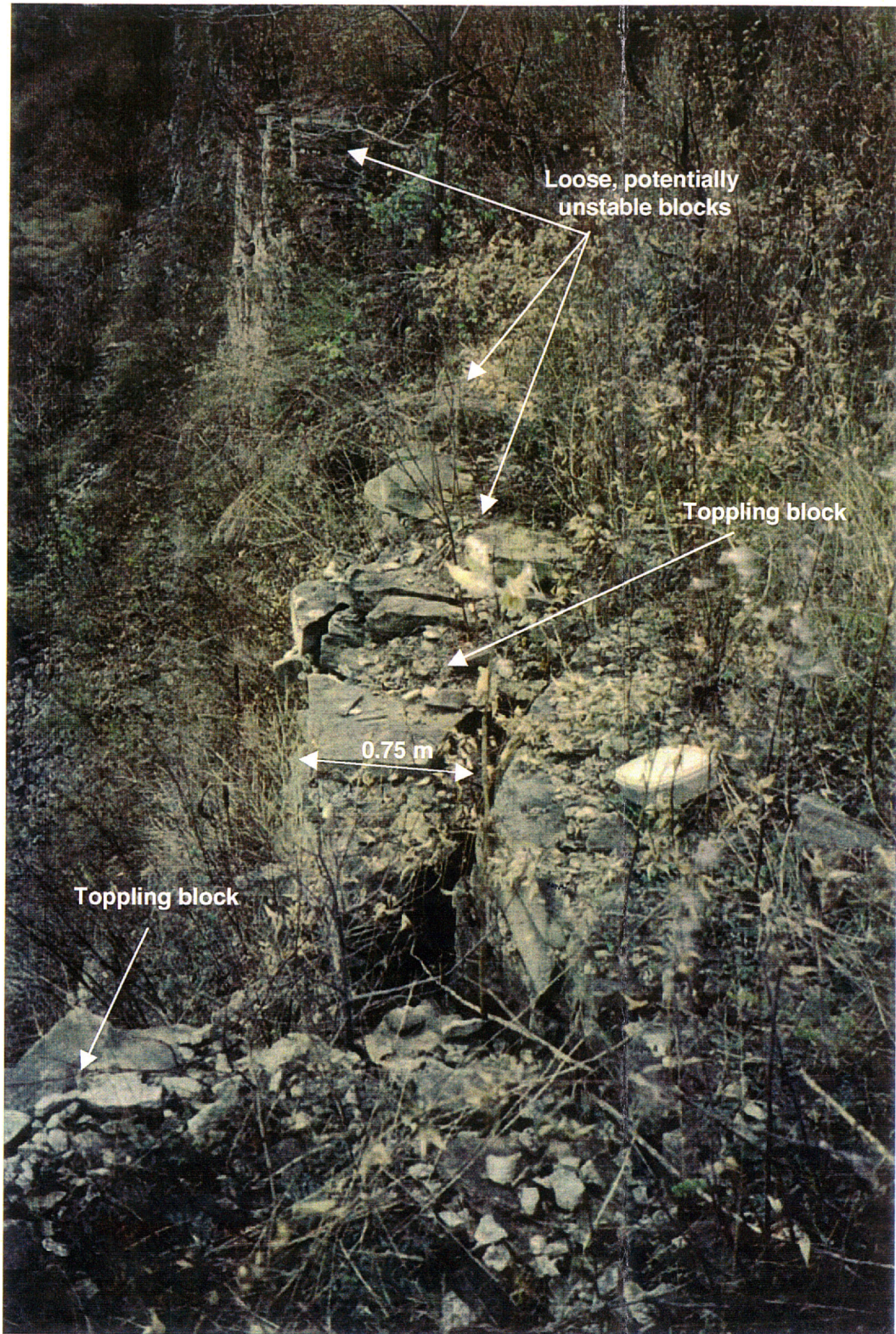
3d) Potential toppling blocks with open tension cracks (Approx. CH 12+545)



**Notes:**  
1) The typical toppling and potentially unstable blocks shown, are to be removed.  
2) Other unstable blocks may become loosened or identified during scaling, and these should also to be removed



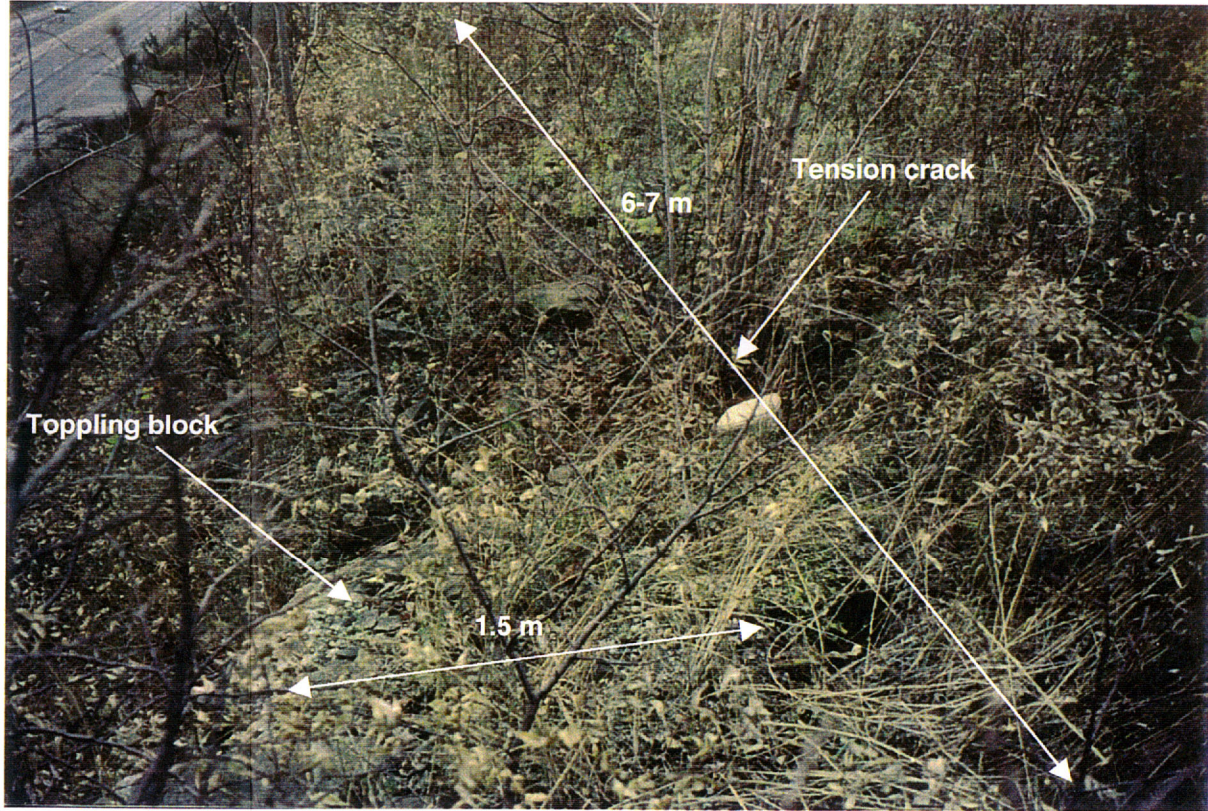
4a) Potential toppling blocks (Approx. CH 12+530)



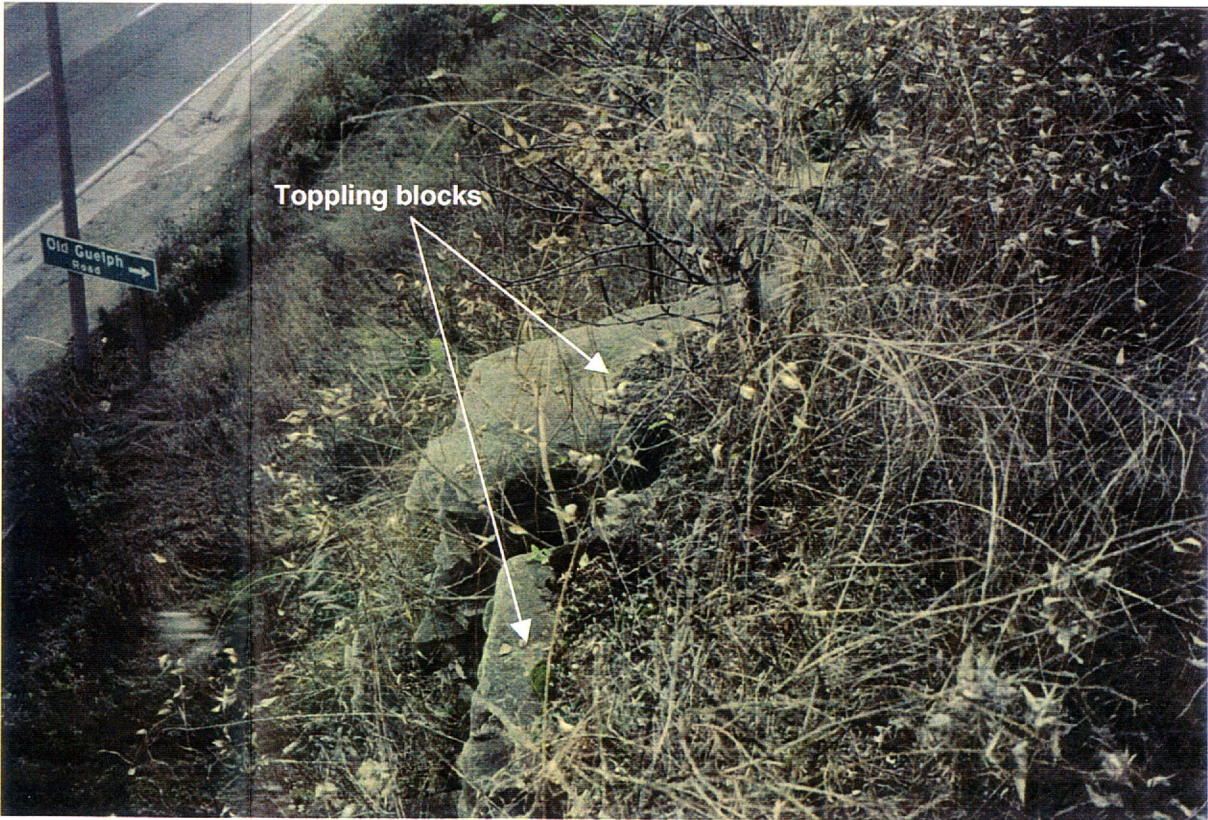
**Notes:**

- 1) The typical toppling and potentially unstable blocks shown, are to be removed.
- 2) Other unstable blocks may become loosened or identified during scaling, and these should also be removed

4b) Potential toppling block (Approx. CH 12+475)



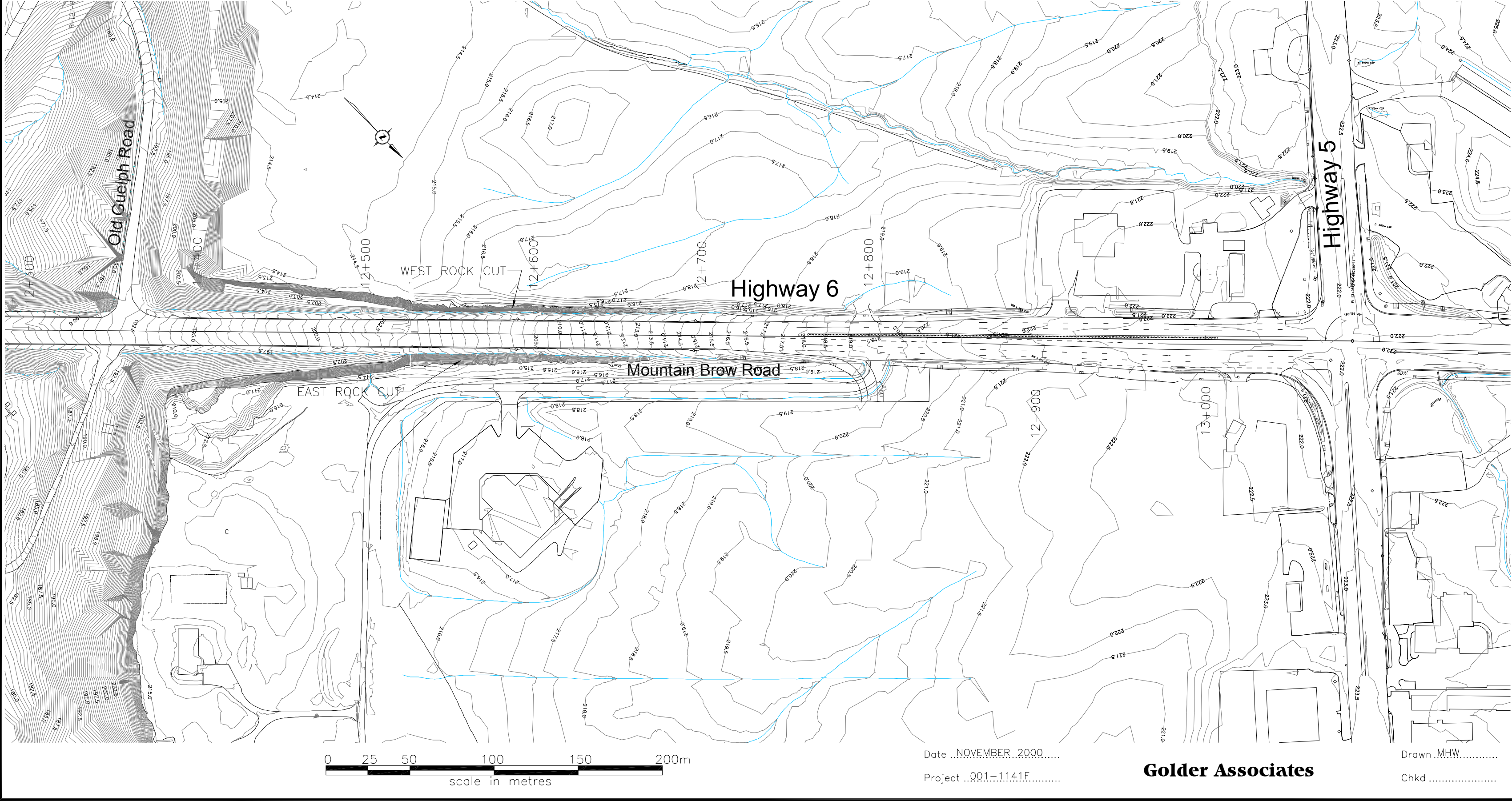
4c) Potential toppling blocks (Approx. CH 12+520)





plot scale 1:1imp

PLOT DATE: August 08, 2005  
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p1141f01.dwg



SITE PLAN

FIGURE 1

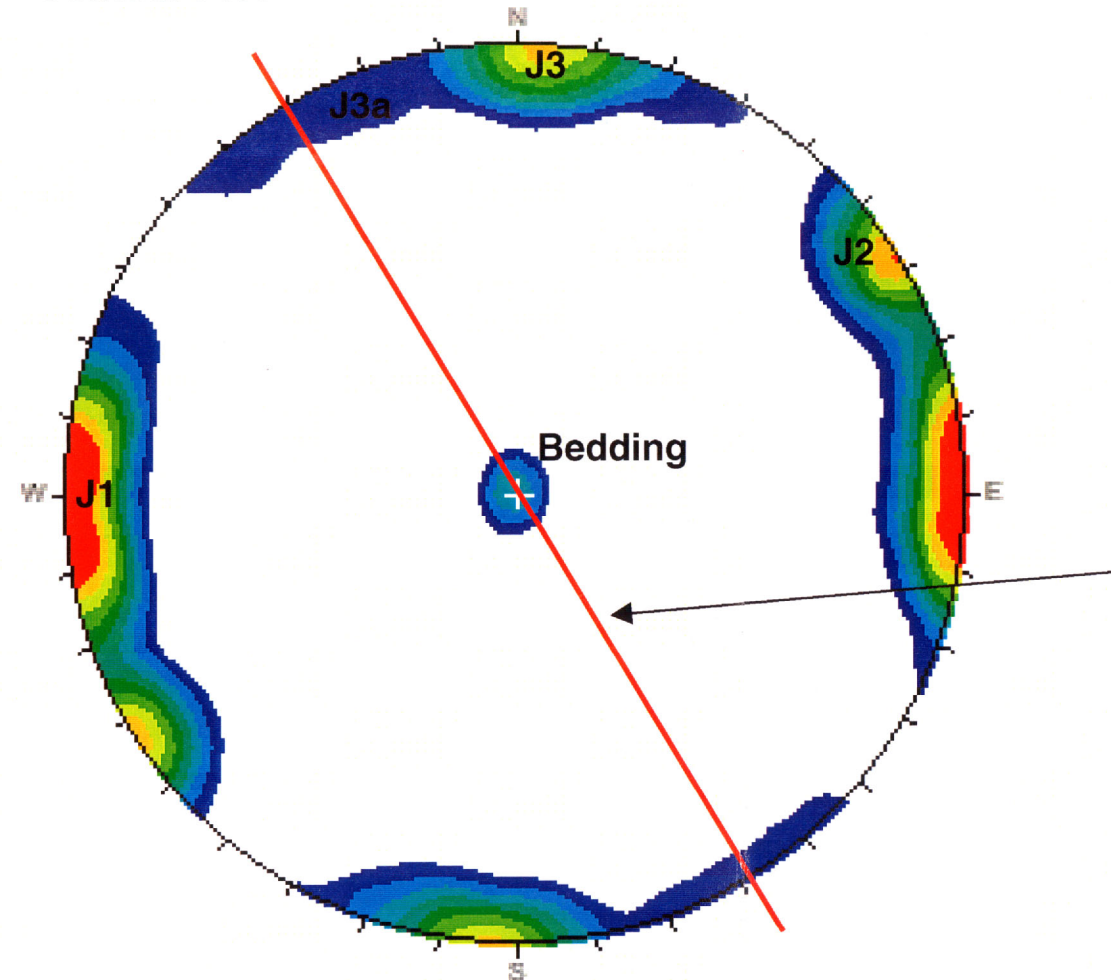
Date ..NOVEMBER..2000.....  
Project ...001-1141F.....

**Golder Associates**

Drawn ..MHW.....  
Chkd .....



Contour Plot



Concentrations  
% of total per 1.0 % area

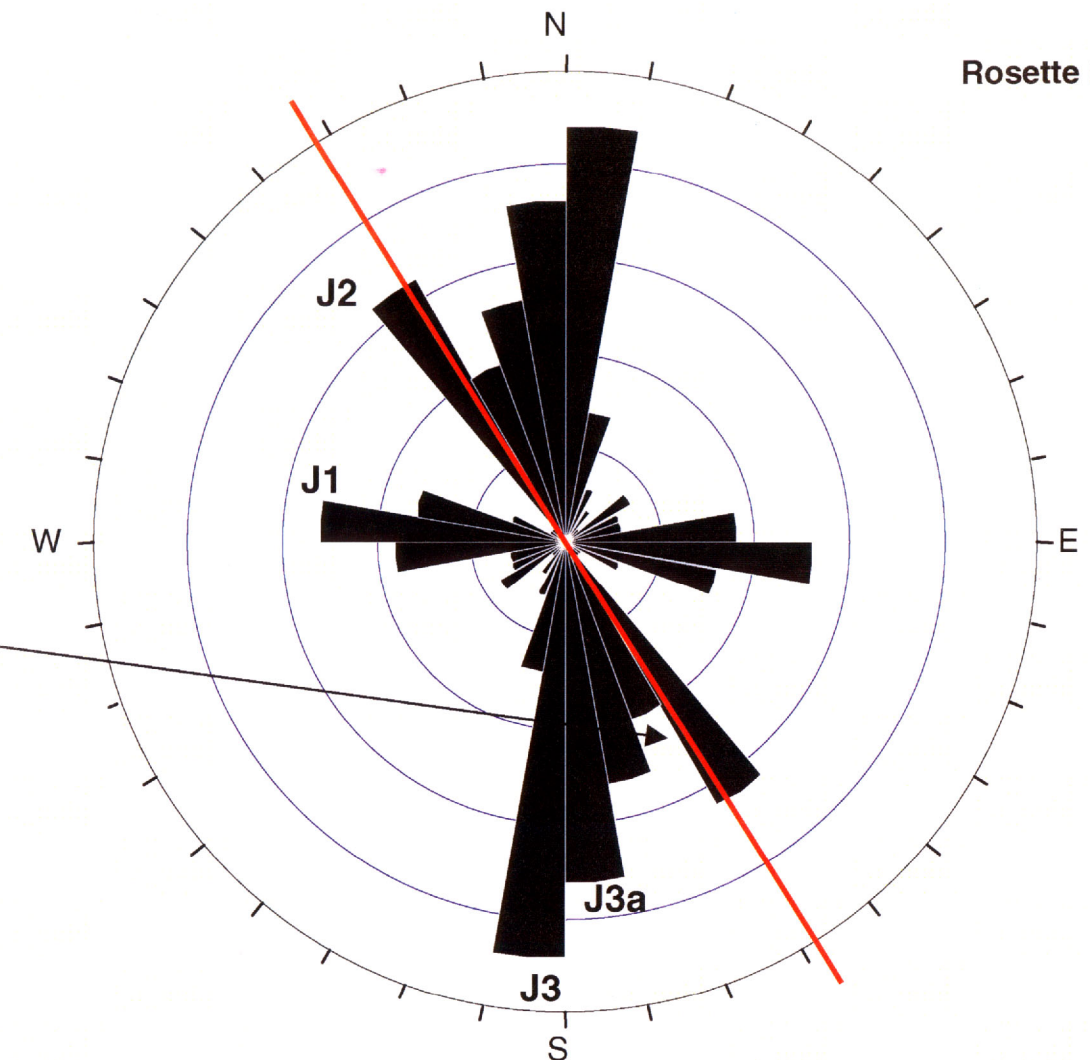


0.00 ~ 2.00 %  
2.00 ~ 3.50 %  
3.50 ~ 5.00 %  
5.00 ~ 6.50 %  
6.50 ~ 8.00 %  
8.00 ~ 9.50 %  
9.50 ~ 11.00 %  
11.00 ~ 12.50 %  
12.50 ~ 14.00 %  
>14.00 %

No Bias Correction  
Max. Conc. = 18.4174%

Equal Angle  
Lower Hemisphere  
148 Poles  
148 Entries

Rosette Plot



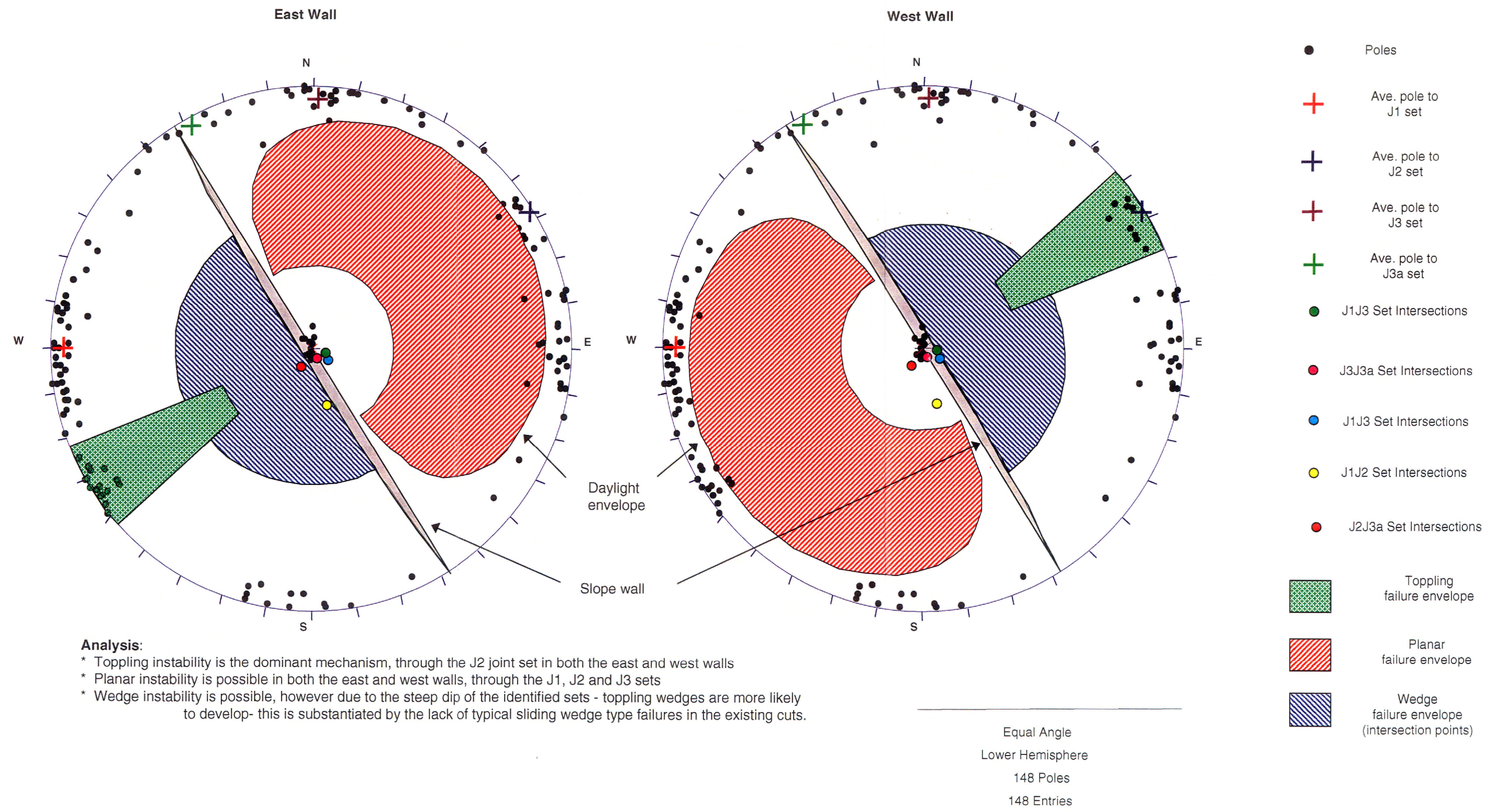
Apparent Strike  
25 max planes / arc  
at outer circle

Trend / Plunge of  
Face Normal = 0, 90  
(directed away from viewer)

No Bias Correction

137 Planes Plotted  
Within 45 and 90  
Degrees of Viewing  
Face





**Analysis:**

- \* Toppling instability is the dominant mechanism, through the J2 joint set in both the east and west walls
- \* Planar instability is possible in both the east and west walls, through the J1, J2 and J3 sets
- \* Wedge instability is possible, however due to the steep dip of the identified sets - toppling wedges are more likely to develop- this is substantiated by the lack of typical sliding wedge type failures in the existing cuts.

**APPENDIX A**  
**STEREOGRAPHIC PROJECTIONS**

Field data derived from structural geological mapping essentially consists of descriptions of various types of geological discontinuities such as joints, faults and bedding planes. One of the most significant aspects of these features is their orientation in space. Whenever mapping projects involve the collection of large amounts of such orientation data, it is necessary to resort to some means of graphically displaying these orientations in order to identify sets of planes with similar orientation. The plotting techniques which are most widely used are called stereographic or equal area projections.

If each of the geological discontinuities is assumed to pass through the centre of an imaginary oriented sphere, then the intersection of the plane with the sphere defines a great circle (see Figure A1) which uniquely orients the plane in space. A line drawn perpendicular to the plane through the centre of the sphere intersects the sphere at two points (poles) which also uniquely define the plane's orientation. Because of symmetry, only half of the reference sphere is required to display all of the orientation data and by convention, the lower hemisphere is used. For convenience, the data on the lower hemisphere is projected towards the zenith through the equational plane and this plane projection (called the stereographic project) is used to conveniently summarize the collection of orientation data.

Any inclined geological plane is defined by its inclination to the horizontal (its dip) and by its orientation with respect to north, which may be defined by the strike or by the dip direction of the plane. The relationship between these terms is illustrated in Figure A1. Note that dip direction is always measured clockwise from north and that the strike line is at 90° to the dip direction of the plane.

A graphical representation of a large number of discontinuities can still be somewhat confusing since individual planes with similar geological origin are rarely perfectly parallel. Lack of parallelism arises from two factors: one is the natural variability between similar geological features in situ, the second is measurement variability arising from the irregularity of surface shape of individual geological features. Hence, unless an extremely large number of data points are collected in the field, point concentrations which define sets of planes with similar orientation tend to be diffuse and difficult to identify.

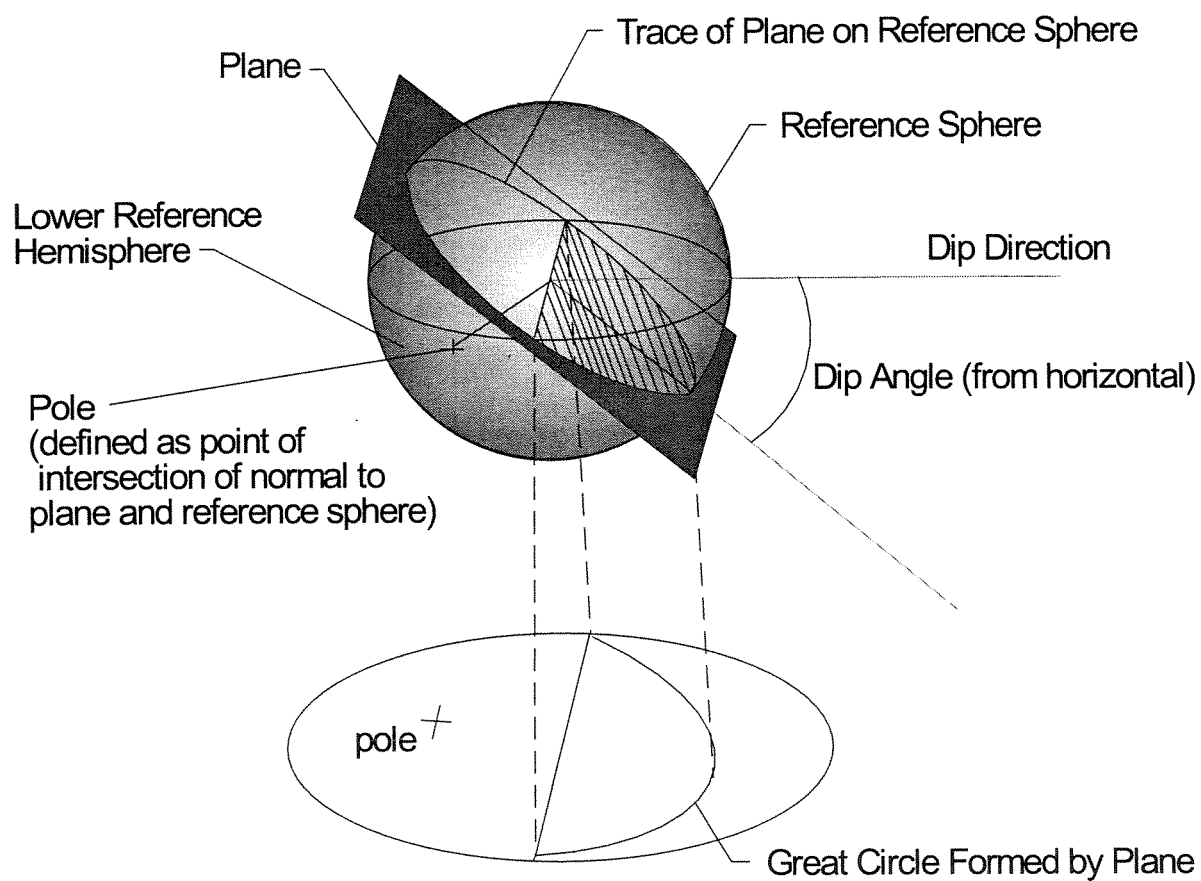
In order to establish overall trends for sets of geological discontinuities, the density of poles as plotted on the scatter diagram are contoured. Contouring may be carried out by hand by counting the number of poles on the stereonet in order to accentuate any patterns of preferred orientation. (Alternatively the method can be readily carried out by computer techniques). The Schmidt method is the most common counting technique although other more sophisticated computational techniques are available. By hand, the counting is carried out by moving a circular counter of 1% of the area of the scatter diagram to successive intersections on a rectangular grid. The number of poles falling within the counting circle is entered at that point. These numbers are then divided



by the total number of poles to obtain the percentage of poles per 1% area of the stereonet and the grid is contoured.

Many of the density diagrams use a slightly different counting technique. Rather than arbitrarily giving each pole a full weight over a 1% area of the diagram as in the Schmidt method, each pole on the reference sphere is assigned a probability distribution corresponding to variations in probable measurement accuracy. Not only does this type of distribution have physical significance, but it produces a more continuous and realistic contoured diagram. Also, the geometric distortion caused by counting on the diagram itself is eliminated by carrying out the counting on the reference sphere.

The bell-shaped probability distribution used for such counting is known as a spherical normal or Fisher distribution. The probability is greatest at the recorded position of the pole, tapering off to negligible size within an arbitrary distance (usually  $10^\circ$ ) in any direction. The significance of this distribution is related to the variation inherent in any geological measurement; rarely will a measurement of discontinuity attitude be out by  $10^\circ$ , occasionally it may be out by  $5^\circ$ , but differences of  $1^\circ$  or  $2^\circ$  from the actual attitude are common. Such a probability distribution for representing each recorded pole therefore reflects the random error inherent in the measurement process, and replaces each discrete pole by a continuous statistical probability distribution centered about the recorded pole.



Lower Hemisphere Stereographic Projection (2-Dimensional)