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REPORT ON

**INVESTIGATION INTO THE CAUSES OF THE
SURFACE SUBSIDENCE
AT GALMOY MINE, CW ORE-BODY,
MARCH 2002**

Consent

Galmoy, Via Thurles
Co. Kilkenny
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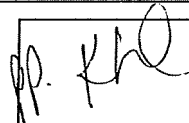
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TABLE OF CONTENTS

1.0 INTRODUCTION 1

 1.1 Mining Operations..... 1

 1.2 Summary of Recent Collapse Events 2

 1.3 Terminology..... 4

 1.3.1 Geological Structures 4

 1.3.2 Rock Mechanics Terminology..... 5

2.0 SEQUENCE OF EVENTS UNDERGROUND 8

 2.1 Events Prior To 2002 8

 2.2 Sequence of Events in January 2002. 9

 2.3 Summary 10

3.0 SEQUENCE OF EVENTS ON SURFACE 12

 3.1 General description..... 12

 3.2 Subsidence Monitoring System..... 13

 3.3 Subsidence Measurements 13

 3.3.1 P-Stope Subsidence 14

 3.4 K-Stope Subsidence 14

 3.5 Summary 16

4.0 MECHANISM OF FAILURE..... 17

 4.1 Underground..... 17

 4.2 On Surface 19

 4.3 Summary 21

5.0 MITIGATION MEASURES AGAINST FUTURE SUBSIDENCE..... 23

 5.1 Immediate Remedial Measures 24

 5.2 Future Mining..... 25

 5.3 Additional Measures for Mining in the Caution Zone of the K Ore-body .. 26

6.0 CONCLUSION 29

 6.1 Cause of the Subsidence on the Whiteswall Road 29

 6.2 Mine Design..... 29

 6.3 Mining in the K Ore-body 30

 6.4 Final Summary..... 31

APPENDIX Ground Displacement Monitoring**LIST OF FIGURES**

Figure 1	General Mine Layout
Figure 2	Detailed Layout for I-, J- and K-Stope
Figure 3	Mine Layout overlain by the trace of Whitewall Road
Figure 4	Chart of Subsidence Measurements
Figure 5	Measurements of Road Survey Points
Figure 6	Graph of Subsidence Readings
Figure 7	Interpreted Subsidence Readings
Figure 8	Subsidence during K-Stope Event
Figure 9	Schematics of K-Stope Subsidence Mechanism
Figure 10	Schematics of P-Stope Subsidence Mechanism
Figure 11	Location of K Ore-body Caution Zone relative to TMF
Figure 12	Limit of Surface Subsidence above CW ore-body

LIST OF PHOTOGRAPHS

Photo 1	Damage to the Whiteswall Road.
Photo 2	Vertical Displacement on the open crack at the top of the hill.
Photo 3	Tension cracks at the north end of the closed section of the road.
Photo 4	The open crack looking south-east.
Photo 5	The open crack in the forested field south-east of the road.
Photo 6	The open crack looking north-west.
Photo 7	The north-westward extension of the open crack in the adjacent field.
Photo 8	The northward extension of the open crack in the north-west field.
Photo 9	The central pressure ridge, looking south. Early February.
Photo 10	The cracked axis of the central pressure ridge, looking north. Early March.

1.0 INTRODUCTION

On January 30th, 2002, a series of collapses underground in the CW Ore-body at the Galmoy Mine resulted in surface subsidence. These events caused physical disruption and temporary closure of the Whiteswall Road in Rathreagh townland. The subsidence coincided with a series of roof collapses and pillar failures in the K-Stope, which then led to further collapses in other areas of the mine. Successive ground falls in the K-Stope resulted in the breaching of a fill barricade and the release of several hundred tonnes of tailings slurry into the mine workings. There were no injuries or damage to equipment.

Golder Associates Ltd. (Golder), was retained by Arcon Mines Limited to investigate these events and was represented by Mr. D. Morrison, M.I.M.M., C. Eng. from the Golder Sudbury office in Sudbury, Ontario, Canada. The initial investigation was carried out from Tuesday, February 5th until Friday, February 8th, 2002 with the primary objective of providing a full description and understanding of these events to the relevant local and national Authorities.

This report presents the best understanding of these events based on the initial investigation and addresses the following:

- the sequence of events underground and on surface;
- the mechanism of failure, underground and on surface;
- the possibility of similar events in the K Ore-body Caution Zone; and
- the measures that need to be adopted in the K Ore-body to ensure safe and controlled extraction of the ore.

To put the mining activities in context, it is necessary to describe the mining operations in the CW Ore-body. To explain the mechanism of failure, it will be necessary to refer to some geological structures that exist in the mine and to explain the specific meaning of terminology used in the science of rock mechanics.

1.1 Mining Operations

Ore recovery in the CW Ore-body at Galmoy Mine is accomplished in two phases. Primary production is accomplished by developing rooms 10 m wide and averaging 5 m high, roughly on a square pattern in an ore zone that is inclined at 7-9° to the south-west, with local rolls up to 30°. Development in the ore-body follows the hangingwall contact wherever possible and undulations of the ore means that ore is sometime left in the floor. Typical stope dimensions are 80m by 50m. After primary production, each stoping block consists of an array of square pillars 5 m by 5 m, surrounded by rib pillars with a few access points. The design of the square and rib pillars was developed at the commencement of mining and was based on an understanding of the rock conditions at the time. This array of square and rib pillars was designed to be stable in the very long term under the geotechnical conditions known to exist

in the CW Ore-body. Backfilling of the mine was intended primarily to decrease the need for surface disposal of tailings, although it is recognised that backfilling of the rooms enhances the stability of the mined-out areas. The pillar design relies on the roofs of the rooms remaining stable, and backfill provides the final guarantee that ongoing stability is assured.

The square pillars were designed to be very stable up to about 6 m high and can still be expected to remain stable up to 8 m high, although such pillars would rarely be created. Stopping blocks in areas of the mine where the ore-body is known to be thicker than average and where pillars can be expected to be greater than 8 m high, are laid out as 6 m square pillars.

Secondary production means the recovery of parts of the rib pillars and benching of the floor. This is scheduled when the filling of the area has been, or soon will be, achieved. Secondary production from rib pillars simply means removing sufficient ore to create an array of square pillars consistent with the local area, 5 m square or 6 m square pillars, depending on their planned height. Benching the floors has the effect of increasing the height of the pillar and so reducing its width:height ratio and making it weaker than before. This too has to be consistent with the design aspects of the given area of the mine so that 5 m square pillars are not higher than 8 m and pillars that are planned to be higher than 8 m should be at least 6 m square.

The mine backfill is a high density slurry consisting of thickened mine tailings, delivered hydraulically at 70% solids through a 4-inch pipeline delivery system with 3 to 5% cement. Once placed and cured, this fill will have a strength of 150-200 kPa.

1.2 Summary of Recent Collapse Events

Beginning around 12.00 noon on Wednesday, January 30, 2002, a series of roof collapses resulted in the complete collapse of the K-Stope in the CW Ore-body of the Galmoy Mine. These extended into the I-Stope and the R-Stopes, as well as some of the surrounding access drifts, principally South Drive 1 (Figure 1).

As a result of successive ground falls in the K-Stope, the backfill barricade in the north-west side of K-Stope was breached, releasing some of the backfill that had been poured into the J-Stope during the periods January 9th to 23rd and January 28th to 30th. This material flowed down the Stopping Block Access Drive towards the sump adjacent to N-Stope and temporarily blocked access to the lunchroom. No personnel underground at the time of these events reported any large noise that would be expected to accompany a single, very large fall of ground. However the personnel in the lunchroom reported hearing the flow of tailings, which arrived in three successive waves.

In addition to these events in the central area of the mine, there were several smaller roof falls and pillar failures in the southern part of the mine. As a result of the loss of the access through K-Stope (K-5 room), there is currently no ventilation exhaust route through the southern half of the mine. Also, as a result of cable damage to two pumps in the southern part of the mine, local flooding temporarily prevented access into these areas. This access was re-established on Wednesday, February 6th, 2002 and as soon as the ventilation route from the southern section of the mine has been re-established, normal production activity will resume in this area.

The complete collapse in the K-Stope appears to have allowed the subsidence of the block of rock above the K-Stope, sliding down along the Main Fissure. The distance from the Main Fissure to the mine abutment in the north-east is about 150 m; the subsidence gradually decreased towards the north-east. The rotational movement of this block then precipitated a similar movement in the block above the I-Stope. However, because the distance from the Main Fissure to the south-western abutment is only around 75 m, the block was unable to subside gradually and mobilised along another fault, the G4 Fault, which facilitated the subsidence of the I-Block.

On surface, the subsidence of the J/K-Block and the I-Block resulted in damage to the Whiteswall Road at the top of the hill, including an open crack, tension (en echelon) cracks typical of surface subsidence and a pressure ridge (Photo 1). Unlike the tension cracks, the open crack had significant vertical downward displacement (150-200mm) (Photo 2). At roughly the same time, other tension cracks appeared some 40m north (Photo 3).

The development of the cracks was first recognised on Wednesday afternoon, January 30th, 2002 and these progressively extended into the fields on either side of the road. The most prominent crack (Photo 4) extended southward into the field to the south-east of the road (Photo 5) towards the access road to the farm building that now serves as a core shack. These cracks indicate that the rock above O-Stope and P-Stope also subsided, but by a smaller amount than the I and J/K Blocks. The open crack also extends northward into the neighbouring field (Photos 6, 7, 8).

By Monday, February 4th, 2002, two pressure ridges also appeared in the road, one close to the top of the hill (Photo 1) and one at the bottom of the hill 23 m to 24 m north of the open crack (Photo 9). The pressure ridges were caused by the tarmac on the road being raised up as the ground underneath it is compressed. The height of each pressure ridge was controlled by the amount of compression taking place. Since it first appeared, the larger pressure ridge at the bottom of the hill continued to develop noticeably, perhaps 150-180 mm. The smaller one appeared to stabilise soon after it first appeared, and remained only 80-100 mm high.

Survey points were established on the Whiteswall Road on Thursday, January 31st, 2002 and these have been monitored regularly since, beginning on Friday, February 1st, 2002. Initially,

the rate of displacement was as much as 35 mm per day for the block that sits immediately above I-Stoppe, but this has subsequently decreased rapidly. The date for the re-opening of the road will be based on the rate of subsidence on the road.

1.3 Terminology

In order to facilitate a detailed description of the events underground in the mine, some clarification of terminology is necessary. Not all the geological structures in the mine have been named and it is useful to introduce a systematic reference for the features in the mine that have, or may, become important in understanding the mechanical behaviour of the rockmass in the future. Also, in the science of rock mechanics, some words carry specific meaning that is not conveyed in normal parlance and it is necessary to explain the specific meaning these terms carry in this context to avoid confusion. Such explanations are presented below.

1.3.1 Geological Structures

The most prominent geological feature in the mine is the main fault, locally referred to as the Main Fissure. The Main Fissure that strikes roughly $300^{\circ}/120^{\circ}$ NW-SE through the middle of the Ore-body, dipping to the north-east (about $83^{\circ}/030^{\circ}$), it is about 2-5 m wide and filled with highly altered, clayey material. There is up to 3m reverse vertical throw on this fault and, it served as a conduit for fluids that resulted in the alteration that is an important characteristic of the rockmass in many areas of the mine. This feature has also experienced lateral displacement as evidenced by the many off-shoot faults angled at about 30° to the Main Fissure, striking $330^{\circ}/150^{\circ}$. These off-shoot faults extend to both the south-west and the north-east of the Main Fissure, but are more pronounced on the west side. The orientation of these faults indicates that the lateral displacement on the Main Fissure was left-lateral, meaning that the block south-west of the Main Fissure moved north-westward relative to the other side which moved south-eastward.

Because of the number and complexity of the Main Fissure off-shoot faults, and their importance in terms of underground mine stability, for the purposes of this report, they will be identified with respect to the mining blocks in which they occur. An off-shoot fault that splits away from the Main Fissure in the K-Stoppe will be referred to as the K1 Fault. In the case of several faults that originate in the K-Stoppe, the most northerly split point will be the K1, the next most northerly K2 and so on. The extension of an off-shoot fault to the south-west or north-east of the Main Fissure will make no difference to this notation. The result may be that parallel off-shoot faults on the west side of the Main Fissure may be numbered G1, G3 G4, G5, G7 and G8 indicating that G2, G6 and G9 extend to the north-east of the Main Fissure. According to this nomenclature, the feature that plays a crucially prominent role in the failures in I-Stoppe and on surface will be referred to as the G4 Fault (Figure 1).

Parallel to the Main Fissure, but to the west, are two more clay-filled features, which will be referred to as the W1 and W2 Fissures, in keeping with the nomenclature for the Main Fissure. They also have a few off-shoot faults and these will be numbered in the same way as all off-shoot faults from the Main Fissure, but the location of the split-point from the W1 or W2 will be sufficient to uniquely identify each off-shoot fault.

Cutting across the CW Ore-body from the SW to the NE are two faults; one in the north and one in the south. These faults strongly influenced the limits of very intense weathering or alteration that has occurred in the ore-body in the north-western and south-eastern areas of the mine. These faults will be referred to as the A-north Fault and the A-south Fault, referring to the alteration effect that they appear to control. The A-north Fault strikes roughly 035°/215°, while the A-south Fault strikes 020°/200°. These faults also have off-shoot faults.

1.3.2 Rock Mechanics Terminology

In rock mechanics, the words 'failure' and 'collapse' have very specific meanings and they are not synonymous. Failure means that a block of rock, such as a pillar, has been subjected to loads or pressures greater than its maximum strength and as a result it can no longer support this load. Although the rock may appear to be more or less intact, with only a few cracks, the rock material has been weakened by over-loading and it is only capable of supporting a significantly reduced load. This is called the residual strength of the rock.

A pillar collapse means the rock pillar has been completely broken apart by the loads applied to it. A pillar that has collapsed has no structural integrity and can carry no load and has no residual strength.

When the compressive stresses exceed the ultimate strength of the rock, the block or pillar begins to fail and sheds the load to adjacent blocks or pillars. When this load-shedding or stress redistribution occurs, the additional stresses that are transferred can result in the ultimate strength of the pillars being exceeded, causing them to fail also. This results in a progressive failure of many pillars, or domino failure. Describing a pillar as 'failed' implies the pillar can no longer carry the load imposed upon it; it does not imply it has completely collapsed. The complete collapse of a failed pillar can be prevented by ground support or confinement by backfill.

When the load on a pillar increases beyond its ultimate strength, the failure of the pillar begins. If the excess load applied to the pillar is then redistributed to adjacent pillars and these pillars have the strength to carry the load without failing, then on-going stability can be maintained. The conditions in the failed pillar remain unchanged, and the whole area remains stable. Such a pillar remains in this 'failed' state but without much further deterioration and it continues to have a small 'residual' strength. If, however, the loads

applied to the adjacent pillars causes them to fail, then the loads imposed on all the pillars will continue to increase as the rockmass above moves downwards. This increased loading causes a gradual deterioration of the pillars and, as they expand or dilate, rock sloughs off the surfaces of the pillars, usually in thin slabs. Since these slabs are thickest at the middle of the pillar, it gradually develops an 'hour-glass' shape. Eventually, the result is the complete collapse of the pillars, so the pillar has virtually no residual strength. In some cases, the rate of deterioration of pillars in a domino collapse can be very rapid, and there is a succession of complete pillar failures.

Even once a pillar has begun to fail, it is possible to prevent collapse by applying some confining pressure around the pillar. This can be accomplished by installing ground support such as rockbolts, installing rebars combined with mesh or shotcrete, or by backfilling around the pillar with tailings. The ground support or backfill limits the progressive expansion or dilation of the rock in the pillar and it requires relatively little confining pressure to inhibit the process of deterioration. Backfill or ground support can significantly increase the effective residual strength of the pillar, and can under some circumstances allow the pillar to accept higher loads than it did at the point of failure, particularly if it is a squat pillar. Significant confinement can be provided by unconsolidated (un-cemented) tailings. The cement that is added to backfill around pillars in a room-and-pillar situation is there primarily to prevent the future liquefaction of the fill and possibly to mine against it. Increasing the amount of cement in the fill will not significantly increase its ability to resist the dilation of rock pillars.

A roof fall or ground fall refers to the displacement of rock from the roof of an excavation. This typically happens because of the pressures or stresses in the roof are tensile or shear stresses that exceed the tensile or shear strength of the rock. The result is that the volume of rock in the roof collapses and the loads are redistributed to other areas. Again, the failed rock can be prevented from collapsing by ground support or backfill.

In a room-and-pillar situation it is possible for a roof fall to precipitate a pillar failure or collapse. Short squat pillars are much stronger than tall thin pillars of the same area. This means that pillars with a high width:height ratio have a greater ultimate strength than those with a low width:height ratio, assuming the quality of the rock is the same in both cases. Clearly, a roof fall between two pillars immediately changes the effective height of the pillars, which results in a decrease of their strength. In this way roof falls can change the effective strength of neighbouring pillars and this can in turn precipitate a domino failure.

Normally, the layout of a room and pillar mine is based on the tributary area theory which assumes that the load or pressure on the pillars is relatively uniform. The factor of safety (or strength factor) of a pillar is the ratio of the pressure on the pillar and its strength. If the factor of safety is two then the strength of the pillar strength is twice the loads that will be applied to it. However, if the rock quality of the pillars are poorer than expected, or the

pillars are smaller or higher than designed, then there it is possible for them to fail. Often the reasons of pillar failure is a combination of all of these factors

Just as a roof fall can cause the failure of the adjacent pillars, the behaviour of pillars can effect the stability of the roof. If two adjacent pillars behave in different ways, one is compressed slightly more than the other, then the roof beam between them will have to bend or flex to accommodate the pillar behaviour. If the roof beam is very strong or stiff, it may be unable to accommodate the amount of flexure, or differential strain, induced by the behaviour of the pillars, and the roof beam will break. (This is particularly true if the roof beam has high horizontal stresses although this is not the case at Galmoy). In such cases, the problem of an unstable roof beam caused by pillar behaviour can be resolved by increasing the span of the room, since a longer beam will be able to accommodate the flexure more easily than a short beam.

Pillar and roof instabilities also take place when the rock strata are changing from a horizontal to an inclined position. The rolling of the ore-body also affects the effective strength or effective stiffness of the pillars because they are subject to inclined pressures rather than the vertical pressure for which they were designed. This again can cause the roof beam to break.

In room and pillar mining there is a complex interaction of roof and pillar stability. Although a roof fall in a single heading can be attributed to a very localised problem, once a roof fall includes two or more adjacent rooms, it will definitely influence the stability of the pillars in the area and ceases to be a simple local stability problem. The complex interaction of roof fall and pillar failure will be referred to in this report as 'a collapse'.

2.0 SEQUENCE OF EVENTS UNDERGROUND

There are two categories of events that preceded the failures of January 30th, 2002. First, there are the various mining activities and incidents that occurred in prior to 2002 that provide the context for the later events and, second, there are the activities that immediately preceded the failures and collapses that occurred on January 30th, 2002.

Most of the mining activity in 2001 in the central area of the mine involved secondary ore production and backfilling. Primary ore production in this area of the mine, had been completed between 1997 and 2000 and the pillars and the roof of the stopes mined during this time remained stable.

2.1 Events Prior To 2002

One of the features of production in the south-east section of the mine (and in particular in P- and T-stopps discussed below) of particular relevance was the highly altered clayey material encountered in the roof, immediately above the ore zone. When the mine excavations broke into this clayey material it proved extremely difficult to control.

Primary production in O-Stope began in 1997 and continued throughout 1998. Mining was initially restricted to the west side of the stope and extraction adjacent to the Main Fissure was delayed. Primary mining of the rib pillar close to the Main Fissure began in late 1999, and in the middle of January 2000, a roof fall occurred in the north-east corner of O-Stope, at the Main Fissure. Production was suspended and no further deterioration occurred.

Primary production in P-Stope began in 1998 and continued into 1999. Between December 1999 and March 2000 secondary production by floor benching occurred in P-Stope, and between December 2000 and January 2001, the southern part of the Main Fissure rib pillar was mined from the west, in the O-Stope. At the end of January, 2001, several small roof falls occurred in this area and these were followed by several small roof falls during the primary production in T-Stope. At the time, these falls were considered to be the result of particularly intense weathering above the roof, conditions that the ground support system was not well suited to controlling. On January 31 2001, a roof fall occurred in the south-east corner of the P-Stope and this subsequently progressed across P-Stope towards O-Stope. On February 15th, the O4 and O5 rooms collapsed. After February 2001, no further production from O-, P- and T-stopps was attempted and filling of O-Stope began in August 2001 following refurbishment of the backfill plant.

The mine layout shows the area of O-Stope that has been filled, along with the adjacent area of P-Stope that was also filled subsequently. The dip of the ore-body to the south-west has the effect of limiting the tightly filled areas to the south-west. In the north-east, the fill creates a 'beach' and cannot be placed tight to the roof until the upper end of the stope is

barricaded and sealed. Variations in the inclination of the stope caused by undulations in the ore deposit means that the extent of the beach varies from place to place. In some cases the mine level plans of filled areas over-represent the confinement that this fill provides to the roof and the upper part of the pillars. In the case of O-Stope, the inclination of the ore-body made it possible to fill the stope tight to the roof but this was not achieved in P-Stope.

During the week of September 24th - 28th, 2001, the rib pillar on the south side of K-Stope was mined through in two places to create a square pillar. Secondary production continued during November 19th - 30th, 2001, when the floor in the South Drive 1 between the K- and T-Stopes was benched out, close to the area where the K-Stope rib pillar had been mined. This created a square pillar with an area of 17 m² and a height of 8 m (Figure 2).

Around the middle of November, the J-Stope was being filled in the west end of the stope, up against the rib pillar bounded by the Main Fissure. This was followed by further filling in the O- and P-Stopes from December 1st to January 9th although the filling in P-Stope would not provide support to the roof of the cave that had previously occurred.

Between December 15th and 31st, 2001, benching of the floor took place in K0 room between K-Stope and J-Stope, prior to backfilling. The benching increased the height of the pillar to 7-8m but with no immediately obvious effect on the pillars.

2.2 Sequence of Events in January 2002.

During the period January 9th - 23rd, 2001, filling in J-Stope recommenced. The fill was placed in the western side of the stope, from a fill pipe position adjacent to the barricade in the northern rib pillar. Close to the pillar bounding the Main Fissure the fill would likely have been tight to the roof. The filling then progressed eastward. On January 23rd, 2002, fill was directed into the top of P-Stope to complete the filling of this area. During this period, there were several noises reported, indicating that some rock failure was taking place in the area (the junction of P-, T-, J- and K-Stopes) and some of the pillars in K-Stope, at the south end of K0, were observed to be spalling. On January 25th, 2002, there was a collapse immediately inside the rib pillar in the south-east side of K-Stope (K2/K3 rooms). The spalling of pillars in K0 and the roof collapse in K2/K3 occurred close to areas where the floor benching and rib recovery had taken place. These events were identified by mine supervision and access to the K-Stope area was restricted on 29th January, 2002.

Although the details can never be known, one possible sequence of the events of January 30th is that a series of roof collapses occurred working south-westward from the collapse of January 25th, 2002, in K2/K3 and joining with the weakening pillars west of K0, close to the area that was being filled. Once there had been a collapse in the south-eastern and south-western boundaries of K-Stope, the roof collapses and pillar failures progressed northward, resulting in a complete collapse of K-Stope. The ground falls in the western part of the stope

caused a breach in the fill barricade and allowed the fill to be released into the mine workings. Personnel underground reported three successive waves of fill a few minutes apart. These must have been induced by three ground falls that each caused a wave of fill that first breached the upper containment structure and eventually swept away the remainder of the barricade.

Following the collapse in K-Stope, the pillars in I-Stope began to deteriorate, except for those pillars to the west of the G4 Fault. There were several small roof falls all along the G4 Fault in the I-Stope, as well as roof falls west of the rib pillar bounding the Main Fissure. The roof falls along the G4 structure extended into R-Stope in the south where there was also spalling from pillars and small roof collapses.

In the South Drive 3, there were a few isolated roof falls, one from the Main Fissure, another to the east associated with a small fault parallel to the Main Fissure, and another at the intersection of S3-south. There was some damage to the rib pillar where it is intersected by a small S1 fault. There was a further fall on the extension of the Main Fissure at the intersection of Xc and X5 rooms in X-Stope.

Another series of roof falls occurred along the western limit of Y-Stope. These falls are coincident with the trace of the X2 fault that splays off the Main Fissure in the X-Stope and trends to the north-east. While the westernmost pillars in Y-Stope show some signs of deterioration, the pillars east of Y2 Drive show no signs of distress.

There is some damage in the T6 room, along the east side of T-Stope and at the intersection with South Drive 1. There is also a series of falls in L0 Access Drive, on the west side of L-Stope, but the adjacent pillars show few signs of distress and the main part of the L- and M-Stopes remain completely undamaged.

2.3 Summary

After primary production in the central area of the CW Ore-body the room and pillar design remained entirely stable.

In January and February 2001 there were a series of roof collapses in O-Stope, P-Stope and T-Stope. The collapses against the Main Fissure in O-Stope and P-Stope led to these stopes being abandoned and ultimately filled, beginning in August 2001. All of these failures were attributed to the inability of the local ground support system to control the conditions. These collapses resulted in subsidence at the LP17 subsidence monitoring station immediately above the P-Stope, of up to 84mm as measured on August 1, 2001, indicating that not just roof falls were occurring, but the pillars were failing and compressing significantly as well.

In January 2002 P-Stope appears to have collapsed more completely, followed immediately by a series of roof collapses in K-Stope which then precipitated a complete collapse of the stope. The instability in the K-Stope then caused instability in the I-Stope and this progressed across O-Stope into the northern part of R-Stope.

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3.0 SEQUENCE OF EVENTS ON SURFACE

3.1 General description

On Wednesday, January 30, 2002, a series of cracks appeared in the Whiteswall Road, one major crack at the top of the hill and some smaller cracks at 3-4 metres down the hill (Figure 3). Cracks also appeared at the bottom of the hill, close to the entrance to the farm buildings south-east of the road. That evening the road was closed and on January 31, 2002, two berms were placed across the road, one at the north end and one at the south end, to prevent traffic from passing the road. Later, a second berm was placed further north, closer to the farm buildings at the bottom of the hill.

The cracks in the road are of two distinct types. One type is a single definitive open crack with a large vertical displacement, initially about 0.15m. This crack is located at the top of the hill, roughly perpendicular to the road. It clearly continues into the fields on both sides of the Whiteswall Road. The other type is a set of en echelon tension cracks oriented across the road with very little vertical displacement. One set of en echelon tension cracks are located 3-4 m below the open crack, and there another set of en echelon tension cracks are angled diagonally across the road, at the northern end of the closed section, roughly 50 m north of the open crack. Around the farm building now used as the core shack, there are fresh cracks in the concrete of the yard and out-houses. On the nw/se track to the core shack, there are some other small tension cracks and again on the sw/ne core shack track, there are other very small cracks. The location and orientation of these en echelon tension cracks roughly define the zone of influence of the subsidence area.

By Monday, February 4th, 2002, two pressure ridges had appeared on the Whiteswall Road between the two sets of en echelon tension cracks. One pressure ridge was located close to the top of the hill and one was located at the bottom of the hill.

The largest amount of subsidence has occurred in the field to the south-east of the Whiteswall Road. The subsidence is slightly greater on the northern side of the Main Fissure and, as the two blocks continued to move downwards, the height of the pressure ridge at the bottom of the hill increased. There is an extension of this pressure ridge to the north-west and south-east, but it impossible to identify it in the fields on either side of the road because of the compressibility of the soil. Although the large crack at the top of the hill is the most pronounced damage to the Whiteswall Road, the actual displacement in this section of the road is smaller than the peak subsidence in the field. However, the extensions of this large crack can be seen in the fields on both sides of the road, extending about 5m on the north-west side and about 100m on the south-east side.

Since the first appearance of the cracks on the road, they have continued to become more pronounced although the rate of increase has been decreasing rapidly. Some subsidence

measurements have been made since December 1997 (Figure 4), but these were subsequently augmented by a set of survey points placed on the road on Friday, February 1st, 2002. These have been monitored regularly since then and the results are shown in Figure 5.

3.2 Subsidence Monitoring System

The array of subsidence stations was laid out to monitor the overall effect of the mine as a whole. Initially, the subsidence stations were laid out on a regular grid at roughly 100m intervals and readings were made every 6 months, following the first reading in December 1997. All stations indicated only extremely small displacements, most likely due primarily to the de-watering of the area.

Over the next three years, some of the subsidence monitoring stations were lost. LP1 and 8 were lost very soon after they were established, LP12 in late 1998, LP5 in 1999 after the Whiteswall Road was re-surfaced and LP13, 14 and 16 were lost some time in 2000/2001. Readings from LP7 and LP19 indicate they are unreliable and do not give an indication of the true subsidence. The result was that by August 2000, most of the active subsidence stations were around the periphery of the mining area, some above the mine abutments and some very close to the mine abutments where subsidence could be expected to be minimal. Only two stations were capable of detecting and monitoring subsidence induced by mining in the central area of the mine. One of these was LP17, located immediately above the boundary between P-Stope and T-Stope, and the other was GPBSM west of I-Stope immediately above G-Stope.

On Thursday, January 31, 2002, ten survey points were established on the Whiteswall Road to better monitor the subsidence that had damaged the road. The first measurements were made on February 1st, 2002.

As a given situation moves from stable towards unstable (or unstable to stable), the appropriate action is to increase (or decrease) the frequency of readings. A discussion of monitoring program, the definitions of stable and unstable displacement rates and the importance of the frequency of the readings presented in the Appendix.

3.3 Subsidence Measurements

In the first two years of monitoring, between December 1997 and February 2000 the subsidence survey detected minimal displacements, peaking at 16mm, most likely primarily reflecting the de-watering of the area (Figure 4). At this time primary production from most of the central area of the CW Ore-body had been completed and there had been no significant subsidence as a result.

3.3.1 P-Stope Subsidence

On August 1, 2001, a subsidence survey was completed and this indicated that while most stations had extremely small movements of a few millimetres, a displacement of 84mm had occurred at the LP17 station (Figure 4). Given that this station lies immediately above the P-Stope and T-Stopes, it was assumed that this increase in subsidence occurred as a result of the collapses that had occurred underground in January and February 2001.

Prior to August 2001, the average displacement rate at the LP17 was 0.157mm/day (Figure 6) which is in the quasi-unstable range and should have initiated more frequent readings (see Appendix). During this period the displacement rate at GPBSM was 0.026mm/day, indicating completely stable conditions.

In January and February 2001, there were a series of collapses in P- and O-Stopes. In the light of the effect of the K-Stope collapse on surface, it is likely that these earlier collapses also precipitated surface movements. Over the period of the collapse in P-Stope, it is possible to calculate that the average displacement rate at LP17 was 0.157mm/day, but it is likely that much of this displacement occurred in direct response to the underground events. Extrapolating the previous displacement rate of 0.037mm/day until the end of January 2001, it is possible to estimate that LP17 would have moved gradually up to 12mm before the P-Stope collapse in January and February 2001 (Figure 7). Of the remaining 72mm (of the 84mm measured in August, 2001), most of this would have occurred as an immediate result of the underground events. Following these displacements the rate of displacement would have been relatively low.

What is very clear from these graphs is that they are of little value in predicting the imminent on-set of instability.

3.4 K-Stope Subsidence

Survey points were established on Whiteswall Road on January 31st, 2002. The survey points S1, S2, S7 S8, S9 and S10 have shown virtually no movement while the survey points S3, S4, S5 and S6 do show significant displacements (Figure 5). From Figure 2, it is clear that points S1, S2, S8, S9 and S10 lie outside the limits of the block movements as indicated by the location of the surface cracks. This explains why these points continued to show virtually no movement following the events of January 30th 2002.

Overall, the surveys of S6 and S3 show displacements around 30mm, while points S4 and S5 have displacements of around 150mm and 210mm respectively. Considering only the LP17 and GPBSM readings from February 2002 onwards, these are consistent with the displacements at the road survey points. The GPBSM shows displacements very similar to S4, which is expected, given the proximity of the two stations. LP17, moved over 0.5m and

the displacements continued to increase until February 4th, 2002, at which point the rate of change began to decrease in accordance with all the other survey points.

Figure 5 shows that points S3, S4 and S5 define the movement of the I Block while S6 and S7 describe the movement of the J/K Block. The graph provides two important pieces of information. Firstly, it appears from these readings that the J/K Block has moved less than the U Block. This is extremely unlikely; the movement of LP17 indicates that the east side of the Main Fissure was moving at a very unstable rate and was doing so before the road stations were installed. Since the P/T Block was moving at these rates, it is very unlikely that simply the J/K Block was stationary at that time. It is more likely that the most of the J/K Block movement took place before the road stations were installed (February 1st, 2002) and before the movement of the I Block began. This fits very well with the understanding of the failure process underground.

Secondly, the relative displacements on the S3/4/5 and S6/7 indicate that the points closest to the trace of the Main Fissure were moving more than the points further away. This indicates that both blocks were rotating in a complementary fashion on each side of the Main Fissure, one consequence of which was the pressure ridge at the bottom of the hill.

Following the initial readings on February 4th, 2002, the displacement rates for S3, S4, S5 and S6 were briefly in the unstable range, although they were installed after the major subsidence event. However, the rate of displacement has been decreasing ever since. By March it was no longer unstable, and it will soon return to the stable range.

Figure 8 shows the details of the displacements at LP17 and GPBSM, the stations that moved the greatest distance during this subsidence event. Between August 2001 and the beginning of February, 2002, there was displacement of 378mm at LP17 and 367mm at GPBSM. The graph indicates these displacements at the average rate during the period before the K-Stope collapse, although the displacements are likely to have occurred in steps corresponding to discrete events underground. Most of this displacement probably occurred after the G4 fault opened up, but before the road survey points were installed and before the co-ordinated readings were taken on February 1st, 2001. Prior to August, 2001, the GPBSM station was completely stable and the LP17 station was probably moving at a very slow rate, having re-stabilised after the P-Stope collapse.

Figure 8 confirms how difficult it is to distinguish the on-set of instability even over a very short period of time using a graphical representation of the information. If it is ever possible to identify imminent instability it can only be accomplished using tabulated values as described in the Appendix.

3.5 Summary

During primary production in the CW Ore-body there was no discernible subsidence beyond that induced by de-watering of the area.

Between February 2000 and August 2001, 84mm displacement occurred at LP17, but most of this (around 72mm) probably occurred in January and February 2001, in response to the underground collapse in P-Stope and part of O-Stope.

Between August 1st, 2001 and February 1st, 2002, 378mm and 367mm of movement were measured at LP17 and GPBSM respectively. Most of this would have occurred following the underground events in late January 2002.

Following this, the displacement rates at all of the moving stations were unstable for a few days. Beginning on February 1st, LP17 had peak displacement rates of 100mm/day and 175mm/day before the rates began to stabilise.

The displacement rates on the Whiteswall Road are currently very small and the first phase of road repairs can soon be made. Continued monitoring of the subsidence above the central part of the mine will make it possible to determine when the road should be finally re-surfaced.

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4.0 MECHANISM OF FAILURE

Since the damage to the underground workings was centred on the K-Stope, the investigation was initially focussed on this area. The complete collapse in K-Stope, the failures in I- and R-Stopes, and nature of the resultant surface subsidence make an understanding of the mechanisms involved in these events relatively easy to develop.

In the light of the events in K-Stope, it has become clear that the collapses in the P-Stope in early 2001 played an important role in the development of the instabilities which culminated in the events of early 2002.

The schematics in Figures 9 and 10 (Figure 9i through to 9viii and Figure 10i through to 10xi) present the sequence of events in P- and K-Stopes, as they are described below.

4.1 Underground

In late 1999, primary mining in the O-Stope close to the Main Fissure rib pillar precipitated a series of roof falls. As a result further mining in this area was discontinued. The first roof falls in P-Stope occurred in the south-east corner, close to the A-south Fault. The roof collapse then progressed northwards resulting in a major collapse of the P-Stope and the western part of O-Stope. Although the collapses started as roof falls, the pillars then collapsed as well, as a result of them becoming taller and weaker. This situation was exacerbated by the very weak material overlying the portion of the pillar in ore. Around the same time there were roof falls in T-Stope during primary production, where any drift wider than 5m was unstable.

To the east of the A-south Fault there was a layer of intensely weathered clayey material with extremely poor rock conditions (Q less than 1). This material particularly affected the T-Stope where there was a layer of clayey material extending several metres into the roof. The same material extended west of the A-south Fault into the eastern side of P-Stope and extended some distance along the Main Fissure into O-Stope, forming a halo of extremely poor ground conditions. This was the main cause of the roof falls and subsequent pillar collapses in the area.

These events can now be interpreted as the beginning of the subsidence above this part of the mine.

At the time, these poor ground conditions were regarded as local instabilities, although occasionally these instabilities were large. They were in fact much more regional than this, and resulted in the redistribution of loads to neighbouring areas. In T-Stope, the extremely poor quality of the roof meant that the loads that were redistributed as a result of the O- and P-Stope collapses could not be transferred to the T-Stope pillars very effectively and so were

redistributed to the eastern abutment of the mine. To the west, loads were redistributed to the O-Stope pillars, which were in good quality rock and relatively large. To the north loads were distributed to the pillars in I-, J- and K-Stopes, and to the south loads were distributed to the R- and S-Stopes. Initially at least, the I-, J-, and K-Stope pillars were sufficiently strong to accept their "own" loads plus loads transferred from P-Stope. Given the intense weathering above S-Stope, the loads would have been distributed further south to the X-Stope, and this may explain some of the instabilities in that area.

The low level of support under the O/P/T block resulted in surface subsidence beginning in January and February 2001, although this was not recognised until August 2001. The filling of O-Stope began immediately and because of the inclination of the stope, it was filled tightly to the roof. Filling progressed into the P-Stope in December 2002, after the J-Stope had been filled. The expectation was that backfill on O-Stope would reinforce the remaining pillars in the area and would complete the stabilisation of the area. There was no fill in T-Stope and the eastern part of P-Stope was not filled tight to the roof.

In the I/J/K stoping area the rib and square pillar layout had remained stable since the end of primary mining in 1998. The ground conditions in the Main Fissure between I-Stope and J-Stope were very difficult and after a few attempts to mine through, a decision was made to leave a rib pillar between these two stopes. The support provided by this rib pillar, given the poor quality of the rockmass in this area, would have been very low. This effectively created a large, mostly unsupported span from the middle of I-Stope (I4 rooms) to the middle of J-Stope (J2 rooms). In addition, some of the pillars in J-Stope were under-sized (less than 25m²) and suffered serious sloughing. Taken together, the poor rock quality in the I/J rib pillar and the small size of the J-Stope pillars, these conditions would have resulted in increased loads being transferred to the adjacent stopes and much of the transfer being to the K-Stope pillars.

Initially at least, the K-Stope pillars could accept the loads being transferred to them. However with this transfer, the minor secondary production in K-Stope was then sufficient to initiate the instability in the whole area. Under normal circumstances, and the K pillars not having to take redistributed loads, the floor benching in K0 or the rib recovery at the south end of K2/K3 would have had no significant effect. However, the particular conditions in K-Stope, made these small changes critical.

Once the failure was initiated in K-Stope, beginning with the roof collapse in K2/K3, the progressive collapse of the area was inevitable. The earlier subsidence of the P/T Block was already dragging on the J/K block. This effect likely drove the first failures along the southern and western edges of K-Stope, and the collapse progressed northwards from there, resulting in a complete collapse of K-Stope.

This sequential collapse allowed the whole block to begin to rotate downwards, dipping to the south-west. This movement would have followed the path of least resistance along the Main Fissure. Once the K Block had mobilised on one side of the Main Fissure, the I Block would have been unconfined. The pillars in the I-Stope were in good quality rock. However some of these were not large pillars when first mined, and subsequently became significantly more highly loaded as a result of the stress redistributions that occurred. As the downward motion on the K side of the Main Fissure continued, it induced a complementary rotational movement of the I Block, dipping to the north-east. This likely caused differential loading of the I-Stope pillars, the first effect of which was a collapse in the north end of the stope where the pillars were smallest, followed by a gradual deterioration of the remaining pillars and several roof falls, especially along the G4 fault. This rotational movement would have opened the G4 Fault and facilitated the rapid downward movement of the block above the I-Stope as the pillars to the east of G4 were loaded sequentially and failed. Unlike K-Stope there was no roof damage except where it was intersected by a fault.

In R-Stope there is similar evidence of simple pillar failure without roof damage. In this case the pillar failures are most obvious north-west of the A-south Fault. There are large collapses along the G4 Fault in the South Drive 2 and the next room south. In R1 room the damage is clearly limited by the A-south Fault, although in R4 the pillar damage extends further south to the As1 fault, off-shoot fault from A-south Fault. Beyond these features to the east and south-east, the damage is minimal until the South Drive 3 is intersected by the Main Fissure. It is clear that the A-south Fault and associated features have played a role in the distribution of pillar failure, just as G4 did in I-Stope, although with no obvious surface expression. Just as in I-Stope, there was no damage to the roof in R-Stopes except where it was intersected by faults.

4.2 On Surface

Beginning on January 30th, 2002, tension cracks began to develop on Whiteswall Road as a result of the downward displacement of the K and I Blocks. However, the distance from the Main Fissure to the mine abutment is 150 m for the K Block and only 75 m for the I Block, which means the rock overlying the K-Stope is more pliable or less stiff than it is above the I Block. Typically, when subsidence occurs, tension cracks appear on the edges of an area of subsidence where the maximum tension, or maximum stretching, occurs. This is exactly what happened to K Block, generating the tension cracks at the north end of Whiteswall Road. In the case of the I Block, the gradual subsidence first created the tensions cracks at the top of the hill, but as the subsidence continued, the block above I-Stope was too stiff to accommodate gradual deflections because of its proximity to the western abutment. There is another fault roughly parallel to the Main Fissure, the G4 Fault, and the I Block opened this feature and dropped a distance of about 0.2m in order to accommodate the subsidence occurring on the other side of the Main Fissure, driven by displacement of K Block. The

deflection of the rock overlying the K-Stope was distributed all the way east to the nw/se farm access track.

The open crack in the road coincides with the trace on surface of the G4 Fault which extends north-west and south-east into the fields on either side. On the north side of the road, after about a 5 m extension to the north, the crack takes a very sharp turn to the east. South of the road, the movement on the G4 Fault continues southward across the field that lies on top of O Block, eventually reaching the farm access track. This lies immediately above R-Stope which has a few large pillars, sufficient to arrest the extension of the displacement on this fault. Underground, the downward displacement on the G4 Fault is very pronounced in the entrance to South Drive 1 and the off-set of about 0.2 m correlates well with the displacements on surface. The lack of damage to the two stope pillars west of the G4, in stark contrast to the damage to the pillars to the east, correlates very well with the impact seen on surface.

The relative displacements at points S3 and S4 confirm the rotation of the I Block, and the relative displacements at points S6 and S7 confirm the rotational movement of the J/K Block. In both cases, the points closest to the Main Fissure show greater downward displacement than the points further away from it. The road survey points that lie outside the crack on the road show virtually no movement and confirm that these areas were not mobilised by the failures and collapses initiated on January 30th, 2002.

The tension cracks and the open crack at the top of the hill occurred as an immediate consequence of the collapses underground. As the surface pillar above I-, J- and K-Stopes began to rotate downwards along the Main Fissure, a pressure ridge appeared on the road at the bottom of the hill, caused by the convergence of the J/K Block and the I Block. Figure 2 shows the location of the compression ridge a few metres west of the trace of the Main Fissure in the ore zone. However, the Main Fissure is roughly perpendicular to the ore-body which dips at about 7° to the south-west, so the compression ridge correlates very well with the projected trace of the Main Fissure on surface.

The second compression ridge at the top of the hill was caused by the behaviour of the I Block and there are two possibilities. One possible mechanism is that unlike the J/K Block, the I Block was not moving as one unit, but was split along the tension cracks. In the early stages of the subsidence, when both the I Block and J/K Block began to rotate on each side of the Main Fissure, those parts of the blocks close to the Main Fissure began to move downward, creating the tension cracks at the top of the hill. Once the G4 crack opened, the top portion of this block moved very rapidly re-compressing the I Block and causing a small compression ridge in the tarmac, just ahead of the tension cracks. The other possibility is that the location of the small compression ridge is at the point of inflection of the I Block and reflects the relative stiffness of the I Block compared to the J/K Block. The strains built up at the surface of the J/K Block are distributed through a longer distance in this block, within the

tolerance of the tarmac. In the shorter (stiffer) I Block the strains cannot be accommodated in the shorter distance and are not within the tolerance of the tarmac, so they result in the compression ridge.

These events occurred over the weekend of February 1st to 4th, 2002, since the compression ridges were not observed prior to Monday, February 4th 2002. Unlike the small compression at the top of the hill, the larger compression ridge at the bottom of the hill continued to increase as the rock overlying the I-Stope and J/K-Stopes continued to subside and to converge. The very small cracks on the farm access tracks and in the farm yard indicate the proximity of the limit of zone of subsidence. Apart from these cracks, there is no discernable evidence of movement beyond this limit (Figure 12).

4.3 Summary

The rib and square pillar layout was stable after primary production without fill in all areas except where the intense weathering affected the roof conditions. In all but these areas, the stopes remained stable even when some of the pillars were smaller or higher than designed, and even when additional loads were redistributed to these pillars. Since the failure and collapses occurred in the central area of the CW Ore-body, the adjacent areas of the mine have remained stable and have experienced only a few local instabilities. This indicates that in general the mine design was not only adequate but quite robust.

The collapse of K-Stope was triggered by secondary production in the stope. The sensitivity of the conditions in K-Stope to secondary production was caused by the redistribution of stresses from the adjacent stopes. This stress redistribution was the result of the roof collapse in O-, P- and T-Stopes and the extremely poor load-carrying characteristics of the weathered material above the ore zone and relatively poor quality of some of the pillars in these stopes. When secondary production began in parts of K-Stope, these small changes were sufficient to initiate the complete collapse of the stope.

The root cause of the problem was the roof falls in O-, P- and T-Stopes that lead to failure of the pillars in these areas, and the redistribution of loads to neighbouring areas. While the room and pillar design was adequate for the normal ground conditions in the mine, it was not adequate in the areas that had much poorer ground conditions, related to the intensely weathered rock.

The presence of extremely weathered material above the ore zone and the resulting roof falls reduced the capacity of the pillar layout to support the blocks of rock above. Under these conditions, very good quality support is required in the back to ensure short term stability (and reduced back spans if necessary), and the timing of secondary recovery and backfilling is critical. Large areas of tight backfill would have preserved the integrity of the roof and

ensured the stability of the pillars. This would have made it impossible for the large blocks above the mine to mobilise in the way they did.

Once the support for the overlying rock had been lost and subsidence began to occur, the blocks found it easier to mobilise along the near-vertical faults in the mine. The large areal extent of the unfilled portion of the CW ore-body and the distance to the abutments made arching across the abutments impossible and when the support of the central blocks had failed, they had to subside.

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5.0 MITIGATION MEASURES AGAINST FUTURE SUBSIDENCE

The most important conclusion to be drawn from the investigation is to recognise the six factors that resulted in the regional instabilities of 2001 and 2002. These are:

- Extremely poor quality rock conditions above the ore zone;
- Effect of stress re-distributions from adjacent stopes;
- Timing of secondary production; and,
- Absence of fill.

Once a regional instability was initiated, the situation was exacerbated by the following conditions:

- Presence of major, near-vertical faults;
- Large areal extent and distance to mine abutments;

In those areas of the mine where the intensely weathered material was very close to the top of the ore zone (and in particular P- and T- Stopes and parts of O-Stope), the mine experienced a great deal of difficulty maintaining the stability of the roofs of the rooms. Once the roofs failed, the adjacent pillars became taller and weaker. The highly weathered (extremely poor quality) rock above the ore zone (that sometimes extended down into the ore-body), also contributed to the poor performance of the pillars. As the pillars failed, the loads they previously carried were redistributed to adjacent areas with higher quality rock. In the O- and P-Stopes, highly weathered material was also present as a halo around the Main Fissure which cuts through the ore-body almost vertically.

As a result of the collapse in part of O-Stope and in P-Stope in early 2001, load was transferred to adjacent areas, to the eastern and western mine abutments, to the southern stopes and to the I-, J- K-Stopes. There is some evidence to suggest that this pillar deterioration and load distribution process may have continued as periodic discrete events over the ensuing twelve months. The presence of the highly weathered material in the Main Fissure between the I- and J-Stopes meant that this area was somewhat limited in its ability to sustain the load redistributed from the P- and O-Stopes and so even more load was redistributed to the K-Stope. It was this over-loading that made the K-Stope so susceptible to the very minor changes in pillar dimensions that occurred with secondary production.

The actual collapse that began at mid-day on January 30th, 2002, was induced by the secondary mining that had taken place earlier in the previous few weeks. The first event of the series was the roof collapse on January 25th, 2002, and at this point the complete collapse of K-Stope became unstoppable.

More fill in the central area would have restricted the movement of the blocks above the central area. There would have been a few small roof falls which would quickly have been arrested by the bulking of the collapsed material on top of the fill. Without fill, once the blocks of rock above the central part of the mine began to move, facilitated by the presence of major near-vertical faults, the subsidence was able to extend all the way to surface. The large areal extent in the central area of the CW Ore-body and the distance to the abutments meant that the potential for arching across the abutments was limited.

There is a broad range of rockmass qualities in the CW Ore-body. The pillars in the higher quality rock performed very well, even when occasionally subject to some stress redistribution and backfill is not inherently necessary in these areas. While it provides added security, particularly in the event of problems developing in other areas where stress redistribution mechanisms may be initiated, backfilling is a lower priority requirement compared with areas where intensely weathered material impacts the stability of the roofs, and in some cases the integrity of the pillars themselves.

From the above discussion it can be concluded that in many cases backfill is not necessary to maintain stability after primary production. In some cases backfill is necessary to maintain stability during secondary production, and in a few areas, backfill is required as an integral component of the mining method. The distribution of the types of ground conditions that require these three different fill regimes are controlled by the distribution of particular geological features in the mine and they are now well understood. This makes it possible to plan the backfill requirements for each section of the mine based on the evaluation of the ground conditions.

5.1 Immediate Remedial Measures

Filling of the I-Stope began on February 15th, 2002. This will reduce any further deterioration of the pillars in I-Stope and will help stabilise the surface subsidence. The J-, O-, and P-Stopes have been filled to the maximum extent they can, and the overlying rock is likely in complete contact with the fill and in some cases failed pillar material (i.e. is completely "sitting-down" on the fill). This is strongly indicated by the fact that rate of subsidence on surface is now very small, and the final control over this will be completed with the final backfilling of I-Stope. Most of G- and H-Stopes have been completely filled, although the pillars in these areas have not shown any signs of significant deterioration. With this in mind, and with the complete collapse of K-Stope, there is essentially nothing to be gained from filling this area. Besides the practical difficulties associated with doing this, it is a relatively small area surrounded by completely backfilled stopes on three sides and an abutment on the other that can all accept additional load transfers if need be.

Rehabilitation of the South Drive 2 and the main access drifts in the south-east area of the mine will begin immediately, as will the development of an access from the Stopping Block

Access Drive to re-create a ventilation route from the southern section of the mine. Once this has been accomplished the principal access drifts through the southern part of the mine can be identified and rehabilitated to provide a secure access. It may be necessary to restrict access through some drifts pending filling and these areas should be identified in the next few weeks and barricaded.

5.2 Future Mining

Rather than indicate a general cause for concern over the overall stability of the CW Orebody at Galmoy Mine, the recent events serve to confirm the validity of the mine design and the general robustness of the current room and pillar layouts in most parts of the mine. Areas in the east and north immediately adjacent to the central stoping blocks that collapsed (such as L- and M- Stopes and F-, G- and H-Stopes) have remained undamaged and the pillars in these areas show few, if any, signs of distress.

What has become clear is the effect that extremely poor ground conditions can have on regional stability and that when these conditions exist, larger pillars, reduced secondary mining or backfill need to be introduced as part of the mining operation. Accordingly the following operational procedures will be implemented.

Stope Stability Assessment: In future, every stoping area of the mine will be subject to an objective assessment which will address each of the six contributing factors individually and collectively. If secondary production from an area is considered, this assessment will be carried out in order to establish the sequence and methodology of production, and the timing of backfilling.

Record Keeping: Much of the ground control information compiled in the course of the investigation into the events of January 30, 2002 was available among the mine technical staff, but the information was not systematically documented nor commonly held. Consequently a system for reporting, recording and distributing ground control information will be implemented. In addition, a strategic review of all ground control information will be made regularly, by a suitably qualified person not involved in the day to day operations at the mine.

Ground Control: The current ground control program at the mine as it applies to the central part of the mine has been adequate for the conditions in most areas. To control the extremely poor conditions created by intense weathering will require additional ground support. The installation of cable-bolts has been considered but the stability problems that have been experienced cannot be controlled by this support technique. They can be controlled by the timely and effective application of mesh-reinforced shotcrete and by limiting the roof span dimensions in areas adversely impacted by poor quality rock.

Backfill: The regional instability that occurred in the CW ore-body could have been controlled by timely and efficient backfilling of some of the central stopes. In areas where the rock quality is extremely poor the capacity of the mine to reliably deliver backfill is essential. The high density slurry plant was refurbished in 2001 and now functions very well and provisions to enhance the performance of the backfill delivery system will be implemented.

Monitoring: The subsidence monitoring program was intended to monitor general subsidence over the mine as a whole and it was not designed to identify subsidence in particular regions of the mine, induced by stope-specific events, as have occurred. However, there is evidence that a subsidence monitoring program designed to accomplish this could have alerted the mine staff to the problems induced by the P-Stope collapse. Consequently, a new monitoring program for tracking surface subsidence will be devised and implemented. The location of the stations will be designed to focus on areas of importance and readings will be scheduled in a manner that makes them relevant to mining activities.

The installation of instrumentation in the underground mine has been considered but will not be routinely employed as a means of mine monitoring. The geotechnical performance of the mine is best monitored by regular assessments of pillar behaviour and by periodic strategic assessments of the records of ground stability problems as described above.

Pillar Assessment: In addition to a review of the ground control data, regular pillar performance assessments will also be made in areas scheduled for secondary production. This is a technique that has been developed by Golder Associates for use in other similar mines and has proven to be very effective in identifying the degree of deterioration of pillars. It involves six classifications of pillars based on their appearance which indicates their likely performance under load.

5.3 Additional Measures for Mining in the Caution Zone of the K Ore-body

Figure 11 shows the location of the proposed Phase 3 Tailings Management Facility (TMF) with respect to the trace of the K Ore-body. All of the evidence from the geotechnical drilling program in the area is that the quality of the rock (both the immediate hangingwall and the ore) in this area (and throughout K Ore-body) is better than just about all areas of CW Ore-body. This has now been confirmed by direct observations of rock exposures underground. Of particular importance is the fact that there is no evidence of any continuous intensely weathered rock in and around the hangingwall contact.

As an additional measure of security against a reduction in the integrity and stability of the foundation of the tailings facility, a Caution Zone will be established around the footprint of the TMF, defined by an angle of influence of 60 degrees from the limits of the proposed tailings facility. The angle of 60 degrees is supported by the evidence provided in numerous

documents and submissions which describe the many other circumstances where mining has been successfully accomplished under similar facilities or bodies of water.

Figure 12 shows the actual limits of the subsidence above the CW Ore-body, as defined by the extent of the tension cracks. The location of these limits of subsidence indicates that the actual angle of influence for the CW Ore-body is very close to 90 degrees and the provision of a caution zone defined by an angle of influence of 60 degrees is conservative.

Within the Caution Zone the following operational procedures will be followed:

Subsidence Monitoring: A program will be implemented to monitor the ground subsidence at selected locations on surface. Roughly 35 stations will be used to provide a detailed record of any ground movements, generally at six monthly intervals.

Cover Drilling: Initial development headings will be advanced cautiously, under the protection of cover drilling, 10m ahead of the face. This drilling will be used to identify and locate any weathered fissures and other geological features and generally to establish the quality of the ground conditions in the area. Two parallel headings will be advanced with one heading kept in front of the other. In the event of poor ground conditions they will be treated in the primary heading before advancing the secondary.

Enhanced Ground Support: The ground conditions in the K Ore-body, as identified by drilling, are superior to the ground conditions in the majority of the CW Ore-body and vastly superior to the ground conditions that precipitated the collapse in the CW Ore-body. However, should poor rock quality be encountered, the openings will be supported by mesh reinforced shotcrete sufficient to stabilise the excavations and prevent pillar failure.

Post-primary Backfilling: Backfilling of the primary stoping areas within the Caution Zone will be completed as a standard procedure before any secondary production is considered. Should adverse ground conditions be encountered, backfilling as an integral part of the primary mining cycle will be implemented. Because of the inclination of the ore zone, it is estimated that about 75% of the mined-out area in the caution zone will be tight filled and the remainder will be filled to within 0.5m of the roof. Tight fill will prevent any roof falls and should they occur in the remaining areas, the propagation of the fall will be arrested as the displaced roof material dilates. All mining and backfilling will be completed prior to construction of the Phase 3 TMF cell.

Stability Assessments: The stability of the stoping areas and the mine pillars will be regularly assessed, using the techniques to be introduced in the CW Ore-body. If identified, problem areas will be monitored or instrumented until such time as a permanent remedy can be implemented.

It should be recognized as a final comment on the stability of future mining of the K Ore-body that even if hypothetically the poor rock conditions that lead to the collapse in the CW Ore-body were encountered in the K Ore-body, the consequences would be completely different. Only minimal additional surface subsidence would result because the K Ore-body is so narrow (only 50m to 80m wide). The nearby abutments afford significant protection to the pillars if any stress redistribution mechanism initiates for some inexplicable reason, without leading to an uncontrolled domino response as occurred in the CW-Orebody collapse.

In summary, the mining precautions described will ensure that the extraction of the ore within the Caution Zone will be accomplished with no discernable impact on the Tailings Management Facility and will ensure its stability in the long term.

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6.0 CONCLUSION

On January 30, 2002 a serious incident occurred in the CW Ore-body at the Galmoy Mine. A series of roof collapses and pillar failures resulted in a complete collapse of the K-Stope, followed by major instabilities in the I-Stope and the R-Stope. As a result of three successive ground falls in K-Stope, a fill barricade was breached causing a release of several hundred tonnes of tailings slurry into the mine workings. There were no injuries or damage to equipment.

6.1 Cause of the Subsidence on the Whiteswall Road

This report has described the events that occurred principally in the K-Stope in the central area of the CW ore-body at Galmoy Mine in early 2002. This stope had become critically loaded as a result of failures in the adjacent stopes, most importantly in the O- and P-Stopes, commencing in early 2001. Given its critically loaded state, secondary mining in the K-Stope was sufficient to precipitate a complete collapse of the stope which led in turn to the subsidence of the block of rock above it.

The fundamental cause of these events was the effect of the extremely poor quality rock above the ore zone in the south-eastern part of the mine, which led to a series of roof collapses and pillar failures in the area. These failures were attributed to the inability of the local ground support system to control the conditions, and their strategic impact on the stability of the central region of the mine was not recognised.

The collapse of K-Stope undermined the block of rock above the stope and caused it to subside. This resulted in damage to the Whiteswall Road at the top of the hill, with a large crack opening up and several smaller tension cracks developing. In addition to this, the tarmac was heaved into a ridge in two places. By the middle of February, 2002, the rate of subsidence above the mine had begun to decrease significantly.

The rate of subsidence will be used to determine when the road should be re-opened, probably in two phases. Firstly, when the rate of displacements is less than 2.5mm per day, the road will be repaired with gravel and made passable for normal traffic. Only once all appreciable subsidence has stopped will the tarmac be replaced.

6.2 Mine Design

The room and pillar layout for the mine was designed to have stable pillars and rooms for the duration of the mine life. This design did not include the use of backfill and the addition of backfill into the mine was recognised as providing an additional measure of long-term stability. The original design was developed prior to the commencement of mining, and was based on the favorable quality of the rock generally found in the CW Ore-body. The

extremely poor rock quality that was found to exist in the south and east of the mine was not specifically accounted for at the time the designs were developed. The effect that this poor quality rock would have on roof and pillar stability was not recognised and appropriate changes to the quality of ground support and the sizes of rooms and pillars were not proactively introduced.

The essential stability of the mine and the validity of the current mine design for much of the mine is confirmed by the fact that despite the serious instability that has developed (centred in the I/J/K and O/P Stopping areas) the remainder of the mine continues to be stable and functions normally. For example, production from the north-west part of the mine has continued almost without interruption and there is no evidence of regional stability problems in this section of the mine. In general, the stopes to the east have isolated roof falls where there are faults, but otherwise show no signs of distress. The southern area of the mine will return to normal activity when the ventilation circuit has been re-established, and will be subject to the operational procedures described in Section 5.2.

At the other end of the spectrum, in the T-Stoppe where the poor ground conditions were the most severe, rooms 10m wide could not be practically excavated and supported and accordingly room widths were reduced to 5m. This proved to be a successful change and was a necessary and appropriate response to the prevailing local conditions.

The measures necessary to prevent a recurrence of stability problems are primarily changes to operational procedures rather than a fundamental re-design of the entire mine. In the future, the rockmass quality will be used to determine areas that require a more conservative room and pillar layout because of poor rock conditions and to determine when it is appropriate to discontinue this mining method in favour of a method that includes backfill as part of the method, e.g. drift-and-fill mining. These guidelines will be developed over the next few weeks and will be applied to all future ore-bodies.

6.3 Mining in the K Ore-body

The characteristics of the K Orebody are significantly different from the CW Ore-body. The ore-body is long and narrow and has none of the geometrical characteristics that contributed to the collapse and resultant subsidence in the CW Ore-body. Drilling indicates it has few, if any, major faults or fissures and the ground conditions in the K Ore-body, as far as they have been determined to date, are known to be superior to the general conditions in the CW Ore-body. Nowhere in the K Ore-body is there any evidence of intensely weathered conditions as encountered in the CW Ore-body.

In the area of the proposed Phase 3 extension to the Tailings Management Facility, a Caution Zone has been established. The limits of the Caution Zone have been conservatively

established using an angle of influence of 60 degrees and the additional measures that will be implemented within this Caution Zone are:

- Subsidence Monitoring
- Cover Drilling
- Enhanced Ground Support
- Post-primary Backfilling
- Stability Assessments

These provisions will ensure that the kind of surface subsidence that occurred as a result of the mining in the CW Orebody will not occur above the K ore-body.

6.4 Final Summary

As a result of the failures in the CW Ore-body a series of measures will be implemented at the Galmoy Mine, designed to mitigate against a future occurrence of the events of January 30th, 2002. Taken together, these event mitigation measures (stope stability assessment, enhanced ground support system, comprehensive ground control records, improved backfill delivery, specific pillar performance assessments and effective subsidence monitoring,) will ensure that the potential for a repetition of these events is extremely low.

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APPENDIX

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APPENDIX

GROUND MOVEMENT MONITORING

INTRODUCTION

Ground monitoring instrumentation can be used for two purposes; to monitor conditions that are expected to remain stable, for example as part of a research program, or to detect conditions that might become unstable. In operating mines the first kind of stability monitoring is seldom applied and when instrumentation is used, it is used primarily to detect the possibility of unstable conditions.

Displacement measurements can be an extremely valuable tool for assessing the relative stability of an area within a mining operation. Displacements can be obtained either by specific instrumentation or regular surveying and they provide absolute displacements, measured in millimetres or fractions of millimetres. A series of measurements can then provide both the incremental and cumulative displacements taking place at a given location and with the time between the readings these can provide the displacement rate.

The goal of any monitoring program is to provide an objective measure of the conditions in an area. This is then included with all the other information and subjective assessments which collectively provide an understanding of the degree of stability of the area monitored. In order to accomplish this, the measurements have to be compared to a frame of reference that defines what is meant by both stable and unstable conditions. Measurements can only provide information, but without a frame of reference the data will not contribute to an understanding of the relative stability of an area.

For example, if the roof of a mine excavation has moved 0.02m (20mm) over the last few weeks how important is this? If the area is an isolated area that is well supported with system that has a capacity of 100mm, then there is no cause for concern. If however, these same displacements take place in the floor of an internal hoist room with a tolerance of 0.001mm then, because of the sensitivity of the equipment, it may well be a problem. Of course a measurement may well indicate that although there is currently no cause for concern, but there will be if the displacements continue for a given period of time. The reason for having a monitoring system is to have prior warning of a developing problem. If it is acceptable to wait until the hoist can no longer function before action is taken, then there is no value in having a monitoring system. A monitoring system is only worthwhile if the results are be used to anticipate problems, so as to plan and schedule some proactive response.

Absolute displacements tell only part of the story, and the relative stability of the ground monitored by instrumentation or survey points is best assessed by the displacement rate. The calculated displacement rates then have to be compared to rates that indicate stable or

unstable conditions. If a particular displacement is the tolerance of a given installation then the displacement rate can indicate how long it will be before the installation is negatively affected. This is most easily done extrapolating a graph of the displacements with time. Generally, the displacements are graphed and the resulting time-displacement curve can be used to estimate the rate of change. However, in most cases the critical changes in displacement rate are very small and are difficult to identify on a graph. Secondly, in assessing the rate of change on a graph, it is essential to be fully aware of the time scale. It is all too common to find time-displacement graphs for two or more instruments being compared on the basis of the shape of the curves, when the graphs have different time scales. It is much safer to rely on the tabulated values for the rate of change at a particular station since this avoids a subjective assessment of the curvature of the graph and makes it possible to recognise when the rate passes a critical level.

EMPIRICAL FRAME OF REFERENCE

From experience of monitoring several hardrock mining situations that have gone from stable to unstable conditions or unstable to stable conditions, Golder Associates has established the following assessment of displacement rates for use as a guideline.

Stable	less than 0.025mm/day
Quasi-stable	between 0.025mm/day and 0.25mm/day
Quasi-unstable	between 0.25mm/day and 2.5mm/day
Unstable	greater than 2.5mm/day

As a given situation moves from stable to unstable (or unstable to stable), the appropriate action is to increase (or decrease) the frequency of readings.

Once a table of readings has been established like the one below, it is relatively easy to identify when the rates of movement pass the guideline values above. Graphically this is extremely difficult to do.

CW ORE-BODY SURFACE DISPLACEMENTS							
DATE	days diff.	LP17	incredmt. differenc e	displ. rate prior	GPSBM	incredmt. differenc e	displ. rate prior
23-Dec-97	n/a	146.081	n/a	mm/day	148.081	n/a	mm/day
24-Mar-98	91	146.075	-0.006	-0.066	148.075	-0.006	-0.066
31-Jul-98	153	146.079	0.004	0.024	148.087	0.012	0.078
18-Dec-98	140	146.075	-0.003	-0.025	148.087	0.000	0.000
25-Mar-99	96	146.075	-0.001	-0.007	148.089	0.002	0.021
17-Feb-00	339	146.062	-0.012	-0.037	148.078	-0.011	-0.032
31-Dec-01	326	146.050	-0.012	-0.037	148.066	0.010	0.032
1-Aug-01	211	145.978	-0.072	-0.342	148.064	-0.002	-0.010
1-Feb-02	183	145.600	-0.378	-2.066	147.722	-0.342	-1.869
4-Feb-02	3	145.300	-0.300	-100.000	147.629	-0.093	-31.000
5-Feb-02	1	145.125	-0.175	-175.000	147.613	-0.016	-16.000
6-Feb-02	1	145.110	-0.015	-15.000	147.602	-0.011	-11.000
7-Feb-02	1	145.100	-0.010	-10.000	147.587	-0.015	-15.000
8-Feb-02	1	145.090	-0.010	-10.000	147.588	0.001	1.000
11-Feb-02	3	145.085	-0.005	-1.667	147.573	-0.015	-5.000
12-Feb-02	1	145.074	-0.011	-11.000	147.566	-0.007	-7.000
13-Feb-02	1	145.065	-0.009	-9.000	147.566	0.000	0.000
14-Feb-02	1	145.060	-0.005	-5.000	147.558	-0.008	-8.000
18-Feb-02	4	145.056	-0.004	-1.000	147.550	-0.008	-2.000
22-Feb-02	4	145.045	-0.011	-2.750	147.546	-0.004	-1.000
Feb 29 02	7	145.035	-0.010	-1.429	147.539	-0.007	-1.000

Any monitoring system has limitations on its performance, for example the error range of the survey or the accuracy of a potentiometer. Within these limits the monitoring method cannot distinguish change and it is necessary to select a monitoring device whose range of operation is suitable for the conditions. In the case of hardrock mines, instrumentation that can detect millimetres is adequate. In addition to the physical limitations of the instrumentation, the other variable is the frequency of the readings. If readings are too infrequent, the most accurate monitoring system will not identify problems until it is too late to react. If readings are too frequent, the monitoring system will be unable to detect any change and may create a false impression, leading to complacency. It is extremely common for a monitoring program to begin with enthusiastic and frequent readings and when these indicate that little is

happening, the readings become less and less frequent. Some time later a major event occurs and prompts readings to be taken after the event has occurred.

FREQUENCY OF READINGS

The appropriate frequency of reading will depend on the given situation at the mine and early anticipation of incipient instability can be extremely valuable in making it possible for mine operators to adjust the mine schedule proactively, rather than simply react to the instability once it has occurred. The frequency of stable readings will depend on the rate at which the system could be changing and the response time of the operation. In the case of regional stability which will change slowly, a frequency of several months is reasonable. In the case of local stability which may change in response to weekly activity, then weekly readings are reasonable. In both these cases the response time of the operation to address potentially unstable conditions will be weeks to months and days to weeks respectively. The demands of the system will then dictate the kind of instrumentation that should be used to monitor the conditions.

If a reading at a station or anchor point gives a measurement and displacement rate that indicates unstable movement, it indicates that the instability began some time before, after the earlier stable reading. What remains unknown is the rate at which change is occurring. If there has been a displacement since the last reading of 60mm two months before, the average rate is about 1mm per day. But the displacement could have occurred the day after the previous reading, and since have stabilised, or it could have occurred the day before the current reading and is now unstable. The only way to distinguish these two extreme cases is to take a second reading a few days after the first, to establish the current displacement rate.

RESPONSE TO UNSTABLE READINGS

The displacement rates presented above indicate two possible conditions; one where no action needs to be taken because the readings are stable, and one where some action needs to be taken because the monitoring system indicates unstable conditions. However, the action to be taken will be determined by mine management. The actual reaction should not be pre-determined but should be developed in conjunction with all the other known information about the area.

Once unstable conditions have been recognised, the basic reaction should be to restrict access to non-essential personnel, and in an area that is no longer required and will have no effect on surrounding areas, it may be permanently abandoned. This will be accomplished by replacing the temporary no-access signs with physical barricades to prevent entry. In an area that is still essential to operations, restricting access will often results in lost production, directly or indirectly. The next decision will be what action is necessary to re-establish stable conditions and how and when this can be accomplished. Unfortunately, the time necessary to

mobilise the forces necessary to cope with the instability can be long, relative to the speed at which situations become unstable. This is where tracking the displacement rates between 0.025mm/day and 2.5mm/day becomes important.

As the displacement rates move out of the stable range towards the top of the quasi-stable range (0.25mm/day) the frequency of readings should move to a twice as often to 3 or 4 times as often as during the stable phase. So six-monthly frequency becomes every 3 months or every 2 months. This will establish the rate of change of the displacement rate and it is possible to use this to project ahead to the time when the readings will become unstable. This is easily done visually using a graph of the displacement rate. This time-to-instability is the best case and small increases in the rate of displacement can bring this time to instability forward very easily.

Once the displacement rates move into the quasi-unstable range the situation is becoming critical. It is at this time that all the work done up to that point can be negated by taking readings too infrequently. In hardrock conditions the situation can change very rapidly and when this happens without any forewarning from the monitoring system, the operation will be in the same situation as one that never had a monitoring system. After such an event it is very common for the monitoring system to be described as useless, which it did become. But the system only became useless when it was not used properly. During the quasi-unstable stage, the level of management that can authorise the appropriate response, (e.g. rehabilitation or filling) should be requesting regular up-dates from the technical staff responsible for monitoring. It is all too common for the technical staff to be regularly presenting valuable information in the form of monitoring results that appears to be unwanted and often goes unheeded by management.

In the quasi-unstable range the frequency of readings should move close to the limits of the instrumentation. This will allow a rapidly changing situation to be closely monitored and good proactive decisions to be made. Again, the rate of change of the displacement rate can be used to project to a time when the situation will be unstable, and knowing the response time of the operations, this will dictate when an action plan has to be put in place and implemented. For example, if the reaction is likely to be rehabilitation of an area with ground support and this will take a 3 days to organise and 5 to implement, then this should be instigated at least 8 days before an unstable displacement rates occurs. If the response to the instability is filling and this will take six weeks to have the area filled and set, then the projection to "unstable conditions" will determine how soon filling should begin.

It is critical to recognise that in the quasi-unstable range the projected time-to-instability becomes shorter very quickly. If the displacement rate is accelerating, then the time-to-instability is getting less all the time and to ignore these projections is to negate the value of the system. In hardrock mining situations, things tend to change quickly at this stage and deciding to delay a reaction at this stage can be crucial. It is very difficult to recover the

situation at this stage. In such cases it would have been as well not to install a monitoring system at all - the situation will become completely reactionary but without the cost of a redundant monitoring system.

The most common reason for delaying a reaction is intuition about the rate of change of the displacement rate and while this may be acceptable in the quasi-stable range, it should be ignored in the quasi-unstable range. For hardrock conditions it is generally the case that the on-set of instability begins slowly and accelerates very quickly. In the later stages, intuition about rates of displacement of even the most experienced personnel count for very little, particularly in the face of the very high cost associated with the implications of unstable conditions in essential areas.

NON-ACCESS AREAS

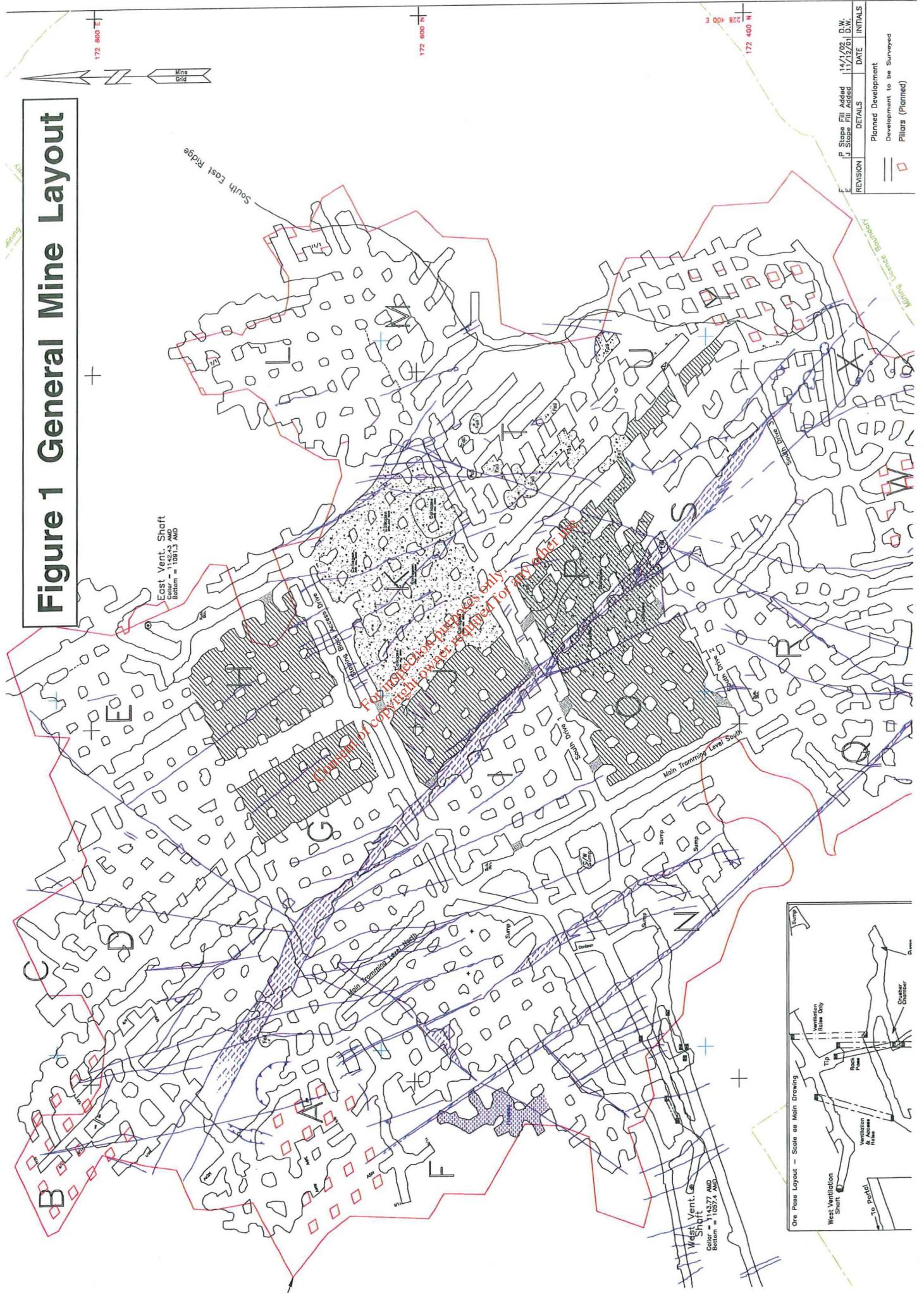
Finally, there is an important distinction between accessible areas and non-accessible areas. In cut-and-fill or room and pillar mining where man-access is always necessary, unstable conditions are synonymous with unsafe conditions. However, in some mining methods, like open stoping, some excavations are designated as "non-access". In these cases unstable conditions are not the same as unsafe, because these excavations are not to be accessed by personnel. Unstable conditions in an open stope may well have implications for the economics of the area but they have no implications for the safety of the area. In these conditions the urgency of taking action in the light of a potential instability is reduced because there are no safety implications.

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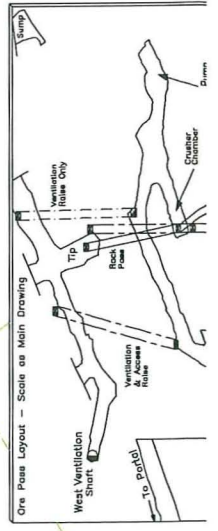
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FIGURES

Figure 1 General Mine Layout



Fibre optic cable placed only. Circumferential concrete water pipe laid for 700 meter W.



REVISION	DETAILS	DATE	INITIALS
P. Slope	File Added	11/17/02	D.W.
J. Slope	File Added	11/13/01	D.W.

Planned Development
 Development to be Surveyed
 Pillars (Planned)

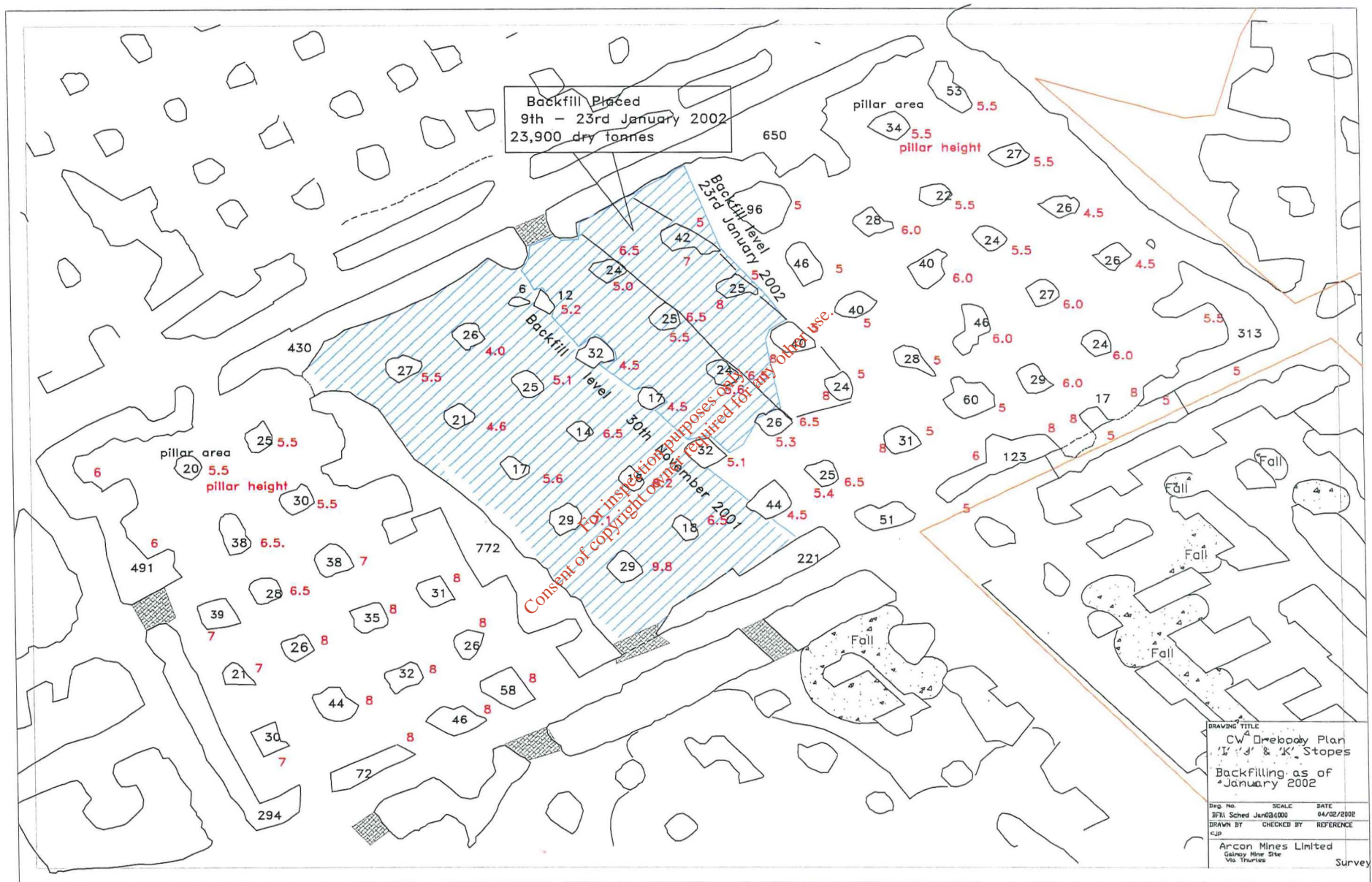
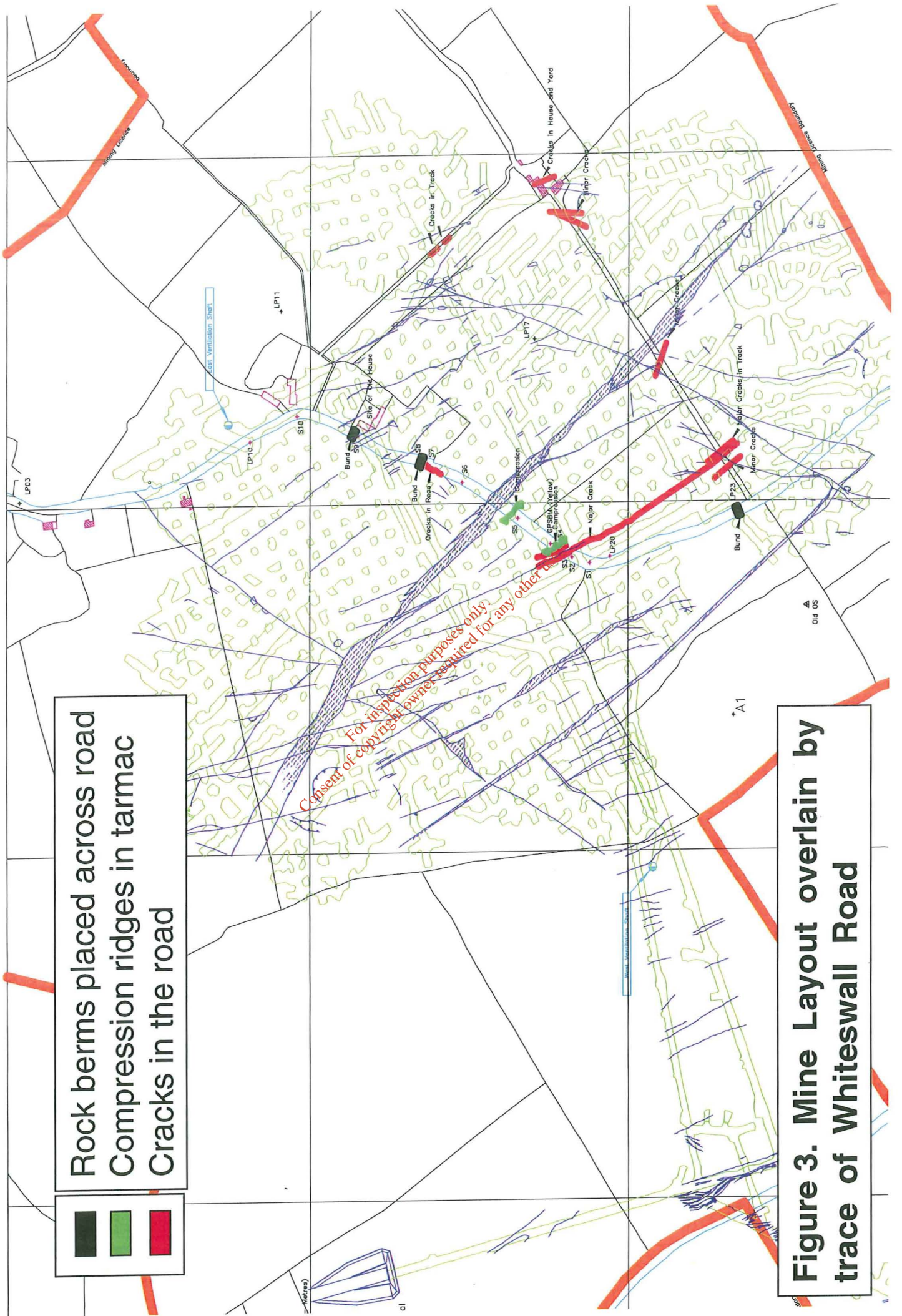


Figure 2. Detailed layout of I-, J- and K-Stopes



SURFACE SUBSIDENCE MONITORING STATIONS																
REDUCED LEVELS																
Surveys From 23/12/1997 to 01/08/2001																
STN. No.	EASTING	NORTHING	BEDROCK Y/.N	REDUCED LEVELS (Metres)							ELEVATION DIFFERENCES (Millimetres)					
				Above Ordnance Datum (Malin)							23/12/97	24/03/98	31/07/98	18/12/98	21/05/99	17/02/00
				12/23/97	3/24/98	7/31/98	12/18/98	5/21/99	2/17/00	8/1/01	3/24/98	7/31/98	12/18/98	5/21/99	2/17/00	8/1/01
GPSBM				148.095	148.089	148.087	148.087	148.089	148.078	148.064	-6.0	-2.0	0.0	2.0	-11.0	-14.0
LP02	227900.569	172926.086	NO	129.351	129.347	129.348	129.347	129.347	129.352	129.350	-4.0	1.2	-1.2	0.2	5.1	-2.3
LP03	228004.900	172928.000	NO	130.284	130.280	130.280	130.280	130.280	130.282	130.285	-4.2	-0.2	0.7	1.8	3.1	2.9
LP04	228110.100	172919.400	NO	129.130	129.126	129.125	129.126	129.127	129.133	129.125	-4.2	-0.8	0.5	1.9	5.9	-8.4
LP05	228007.100	172849.400	YES	132.574	132.567	132.567	132.566	132.569			-6.9	-0.3	-0.9	2.9		0.0
LP06	228223.000	172827.100	NO	132.808	132.803	132.805	132.804	132.806	132.807	132.800	-5.0	1.6	-0.8	2.5	1.1	-7.4
LP07	227588.000	172743.600	NO	138.991	138.984	138.984	138.978	138.985	138.976	138.966	-6.7	-0.1	-6.0	6.5	-8.9	-9.7
LP09	227916.456	172774.234	YES	131.131	131.127	131.129	131.124	131.124	131.123	131.110	-4.3	2.3	-5.5	0.4	-0.6	-13.3
LP10	228046.100	172747.400	YES	139.953	139.948	139.948	139.948	139.949	139.945	139.941	-5.4	0.5	-0.2	1.2	-3.6	-4.5
LP11	228139.800	172722.900	NO	140.922	140.917	140.918	140.918	140.923	140.917	140.911	-4.7	0.4	-0.1	5.0	-5.6	-5.9
LP12	228363.400	172723.700	NO	132.625	132.619						-6.4					
LP13	228038.600	172649.400	YES	142.383	142.377	142.376	142.375	142.378	142.374		-6.0	-0.7	-1.4	3.2	-4.6	
LP14	228005.300	172558.300	NO	144.225	144.220	144.218	144.217	144.219	144.209		-5.5	-1.0	-1.5	2.0	-10.2	
LP15	227670.200	172519.400	NO	136.892	136.885	136.886	136.888	136.889	136.891	136.889	-7.2	1.5	1.7	0.6	2.1	-1.6
LP16	227918.600	172498.200	YES	148.595	148.586	148.585	148.580	148.592	148.586		-9.2	-0.8	5.0	2.3	-5.8	
LP17	228117.700	172523.900	YES	146.081	146.075	146.079	146.075	146.075	146.062	145.978	-6.1	3.6	-3.4	-0.7	-12.4	-84.1
LP18	228376.400	172526.100	NO	139.176	139.171	139.175	139.175	139.175	139.177	139.173	-4.6	4.0	-0.8	0.1	2.0	-3.7
LP19	227491.100	172468.300	NO	137.966	137.964	137.964	137.965	137.964	137.964	137.965	-1.9	0.0	0.5	-0.8	0.6	0.6
LP20	227961.300	172464.500	NO	150.728	150.721	150.722	150.723	150.726	150.717	150.710	-7.1	0.9	1.2	3.1	-9.2	-6.9
LP21	227661.000	172423.300	NO	139.550	139.543	139.543	139.546	139.547	139.547	139.543	-7.0	-0.3	3.1	1.6	-0.5	-3.9
LP23	227995.400	172365.300	NO	157.705	157.698	157.701	157.703	157.707	157.693	157.685	-6.8	2.6	2.1	4.1	-14.2	-7.7
LP24	227669.900	172332.000	NO	140.958	140.957	140.957	140.958	140.958	140.957	140.957	-0.5	-0.2	1.3	-0.3	-1.1	0.0
LP25	227830.800	172345.400	NO	154.487	154.483	154.482	154.485	154.488	154.478	154.468	-4.5	-0.4	3.1	2.7	-9.9	-10.0
LP26	227926.500	172310.100	YES	161.730	161.730	161.730	161.735	161.740	161.724	161.713	0.0	0.0	4.5	4.9	-15.7	-10.9
LP27	228118.500	172293.800	YES	151.570	151.562	151.565	151.566	151.571	151.560	151.550	-7.8	2.3	1.2	5.1	-11.2	-9.6
LP28	228335.000	172372.000	YES	141.760	141.756	141.758	141.756	141.757	141.757	141.754	-4.3	2.5	-1.8	0.6	0.5	-3.4
LP29	227549.500	172265.400	NO	137.270	137.270	137.270	137.270	137.270	137.270	137.270	0.0	0.0	0.0	0.0	0.0	0.0
LP30	228038.000	172288.600	NO	156.736	156.729	156.730	156.731	156.737	156.724	156.716	-7.5	1.8	1.0	5.5	-12.7	-8.2
LP31	228235.200	172305.600	NO	142.567	142.562	142.566	142.565	142.565	142.564	142.560	-4.8	3.5	-0.8	-0.1	-1.1	-3.6
LP32	228027.700	172193.100	NO	155.948	155.941	155.944	155.944	155.949	155.936	155.929	-7.5	3.2	0.7	4.6	-12.5	-7.5
LP33	227947.100	172122.600	NO	146.425	146.420	146.420	146.423	146.426	146.420	146.416	-5.1	-0.3	3.0	3.7	-6.1	-4.2

Notes

- LP01 Lost on Kavenagh's Land
- LP08 Destroyed when CCIL Magazine was Dismantled
- LP12 Ploughed Out
- LP07 and LP19 are Unstable Ground on the Lanscape Berms
- LP05 Lost Due to Roar Resurfacing
- LP13 LP14 and LP16 Lost in 2000/2001

Figure 4. Chart of Subsidence Measurements

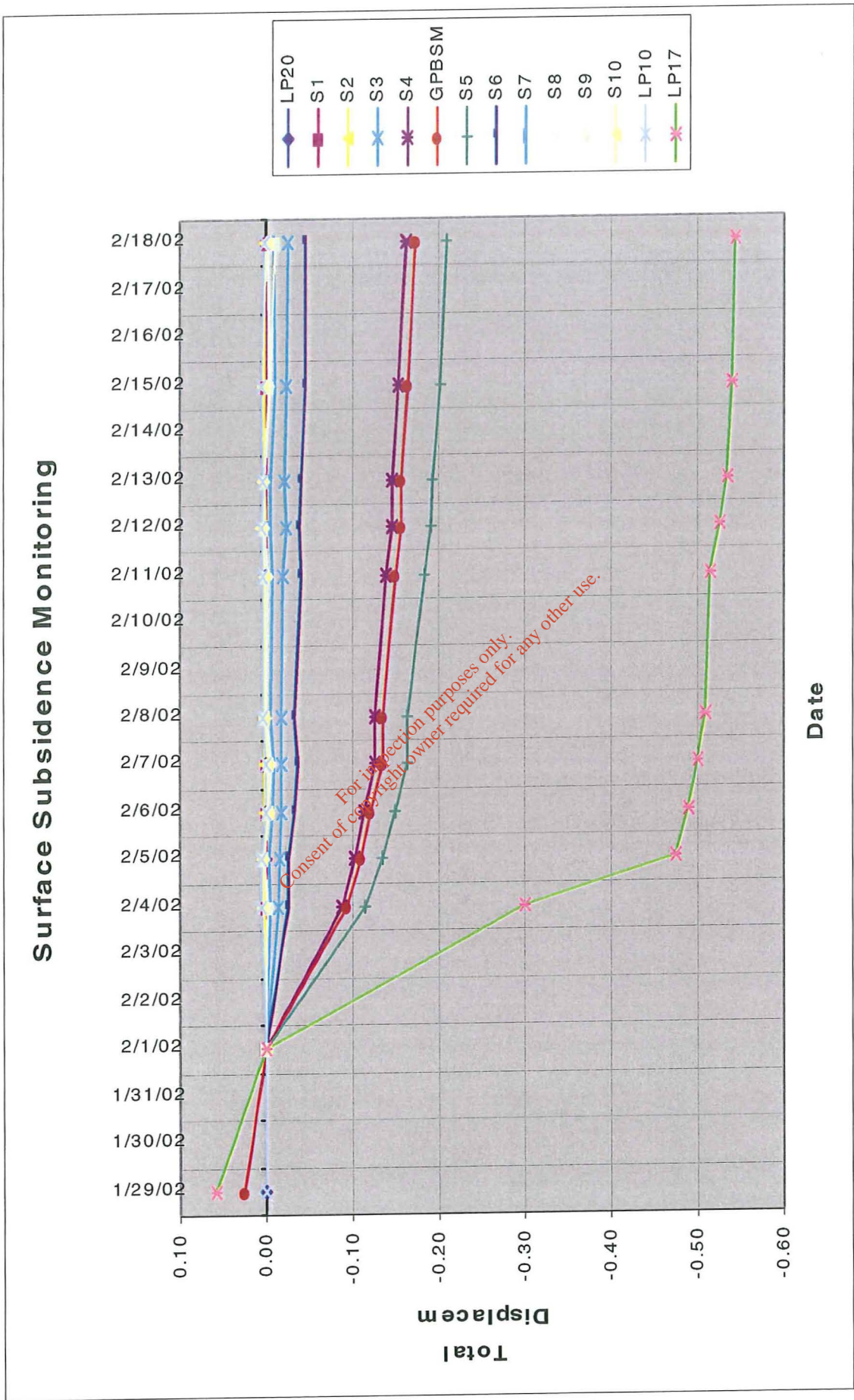


Figure 5. Displacement at the Road Survey Points

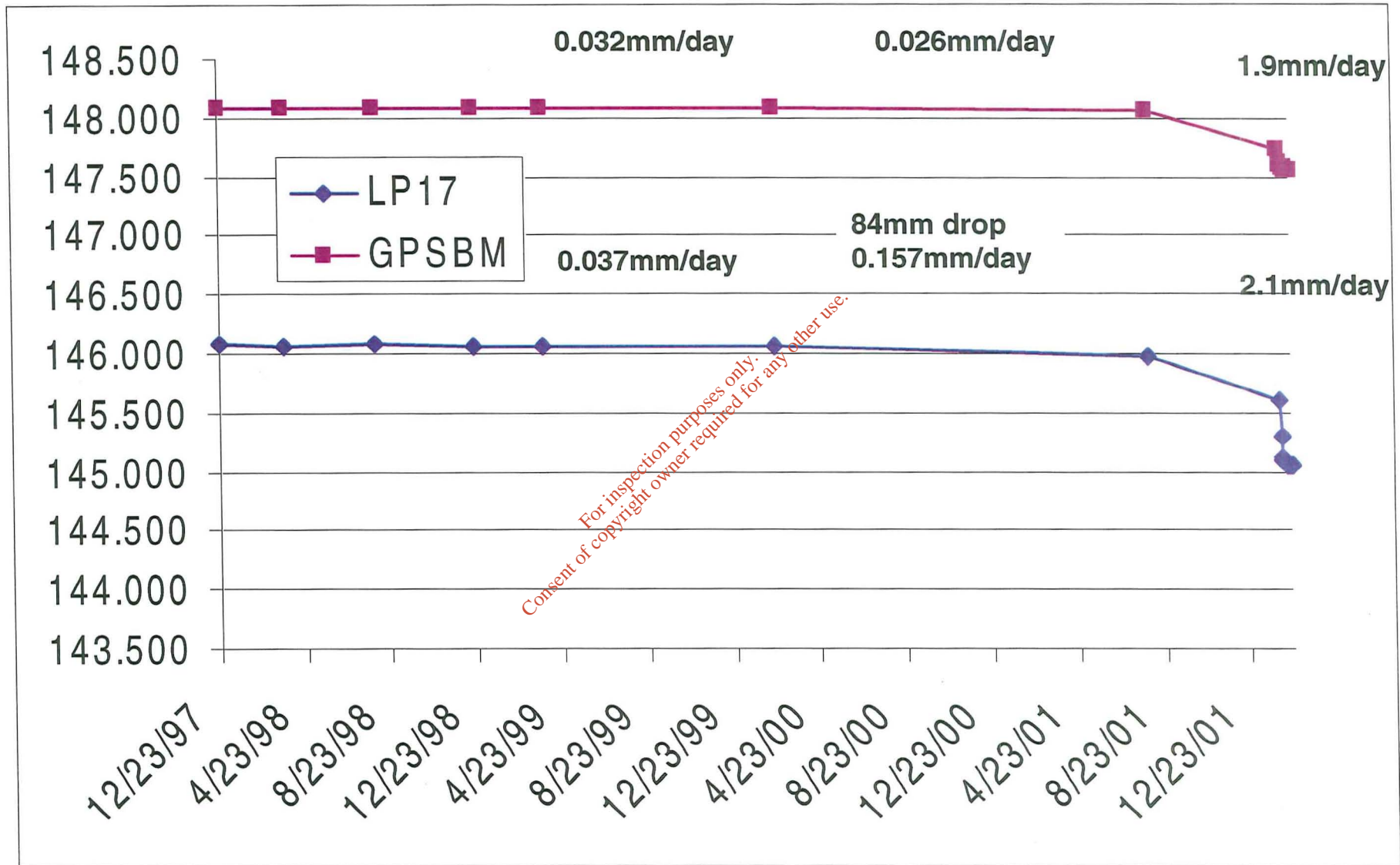


Figure 6. Graph of Subsidence Readings

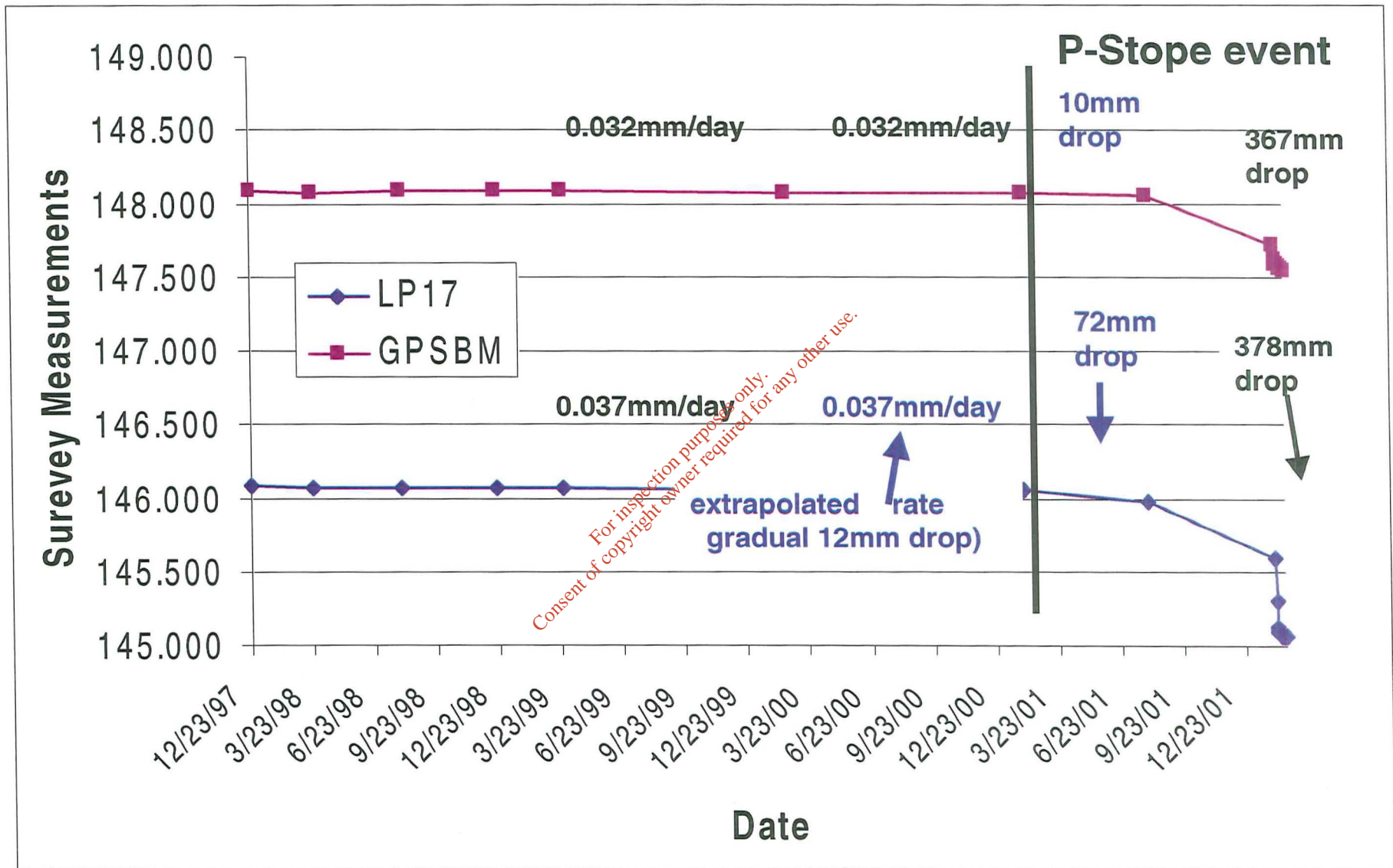


Figure 7. Interpreted Subsidence Readings

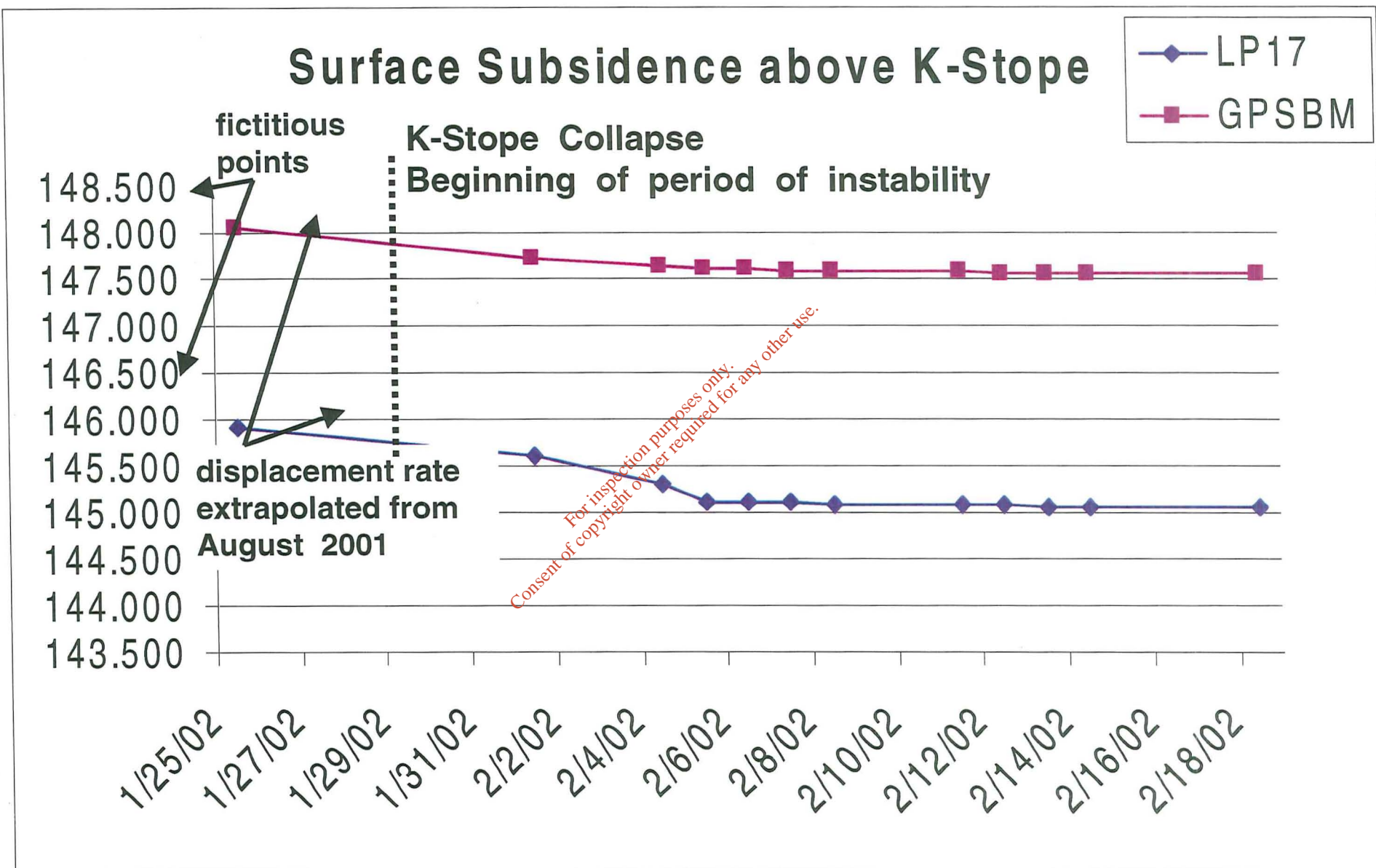


Figure 8. Subsidence during K-Stope Collapse

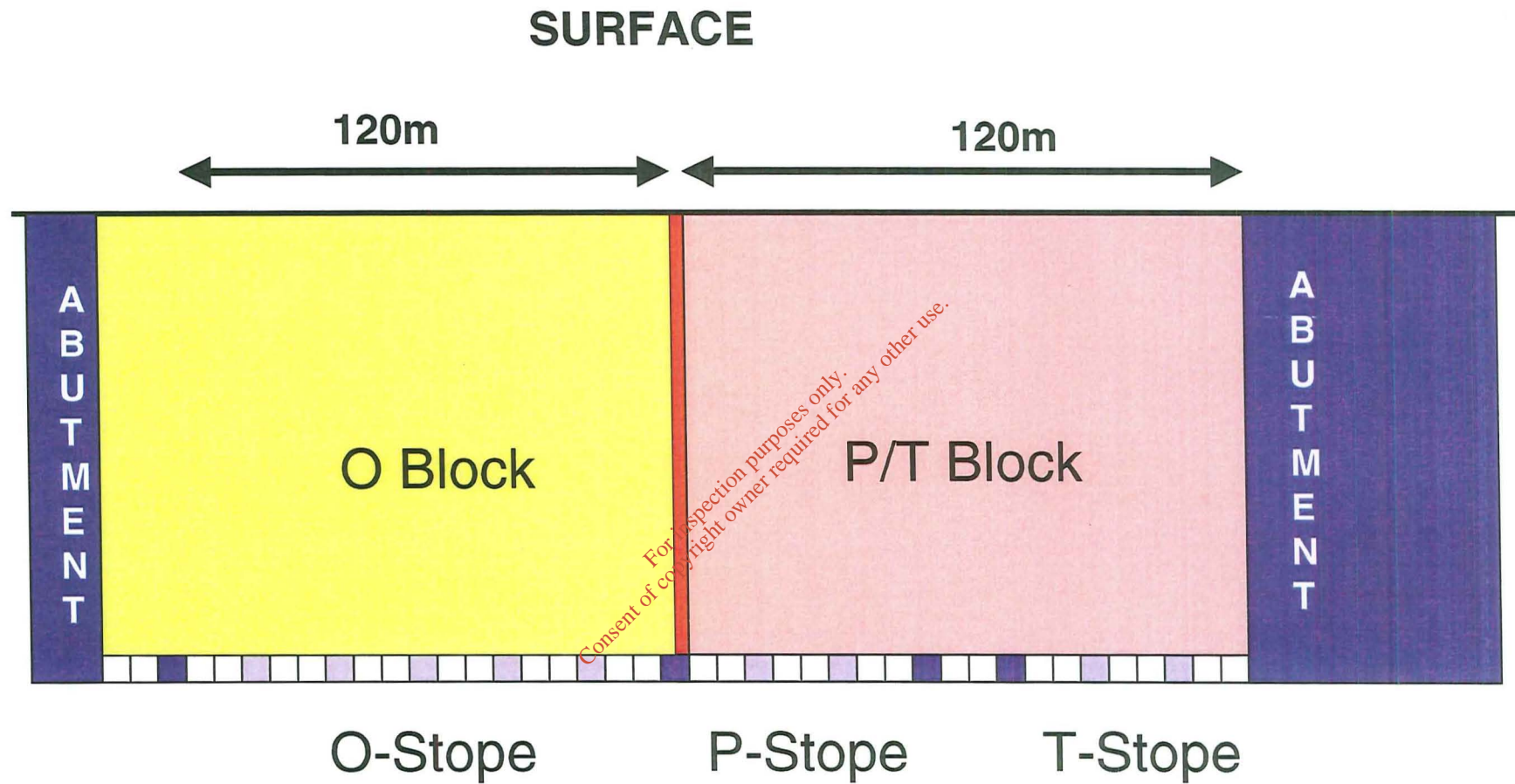


Figure 9. i) Schematic showing section through O/P/T Stopping Area, with Main Fissure extending to surface.

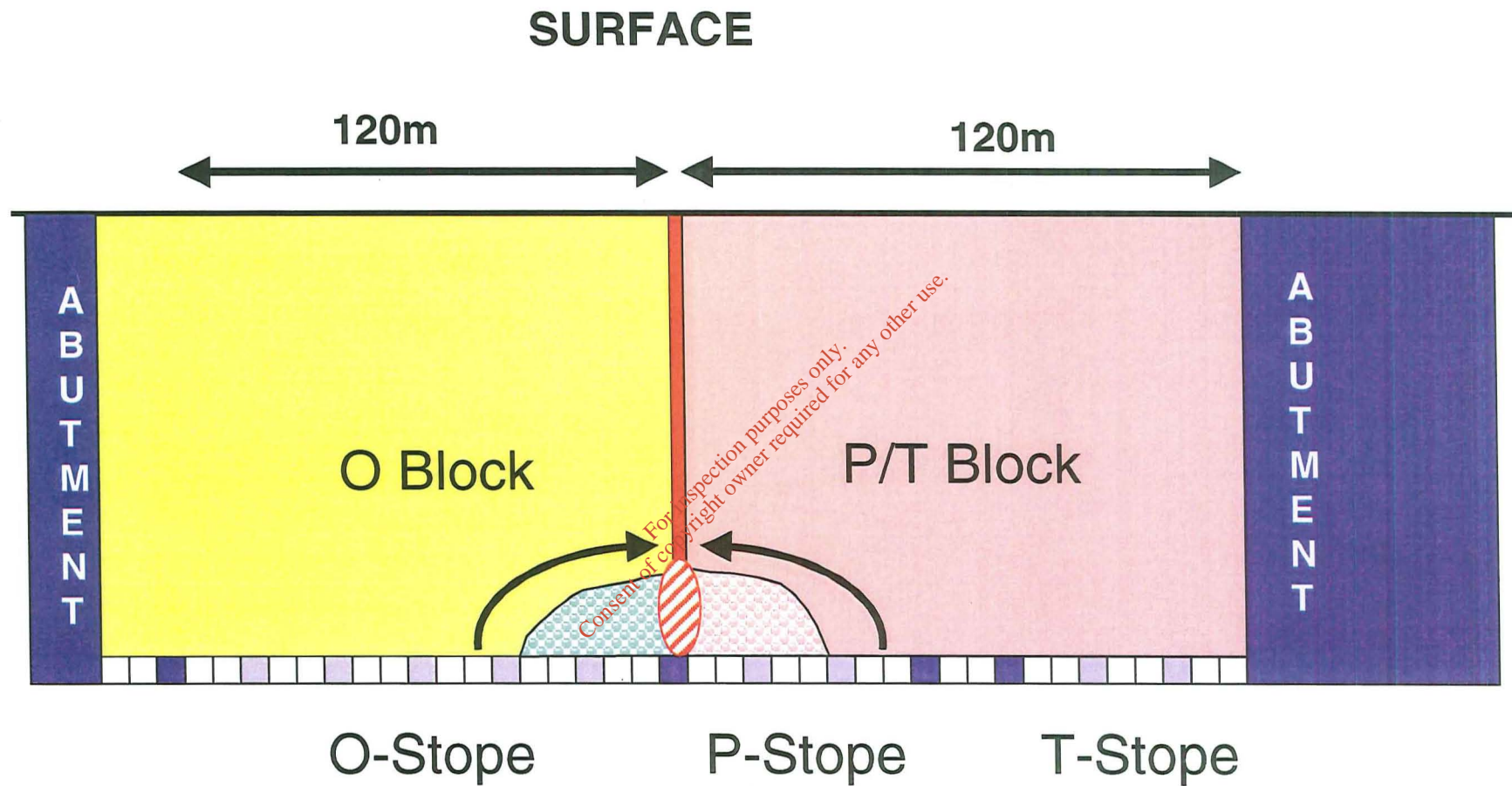


Figure 9. ii) Showing collapse along the Main Fissure in O-Stope and in P-Stope, with redistribution of stresses to adjacent pillars.

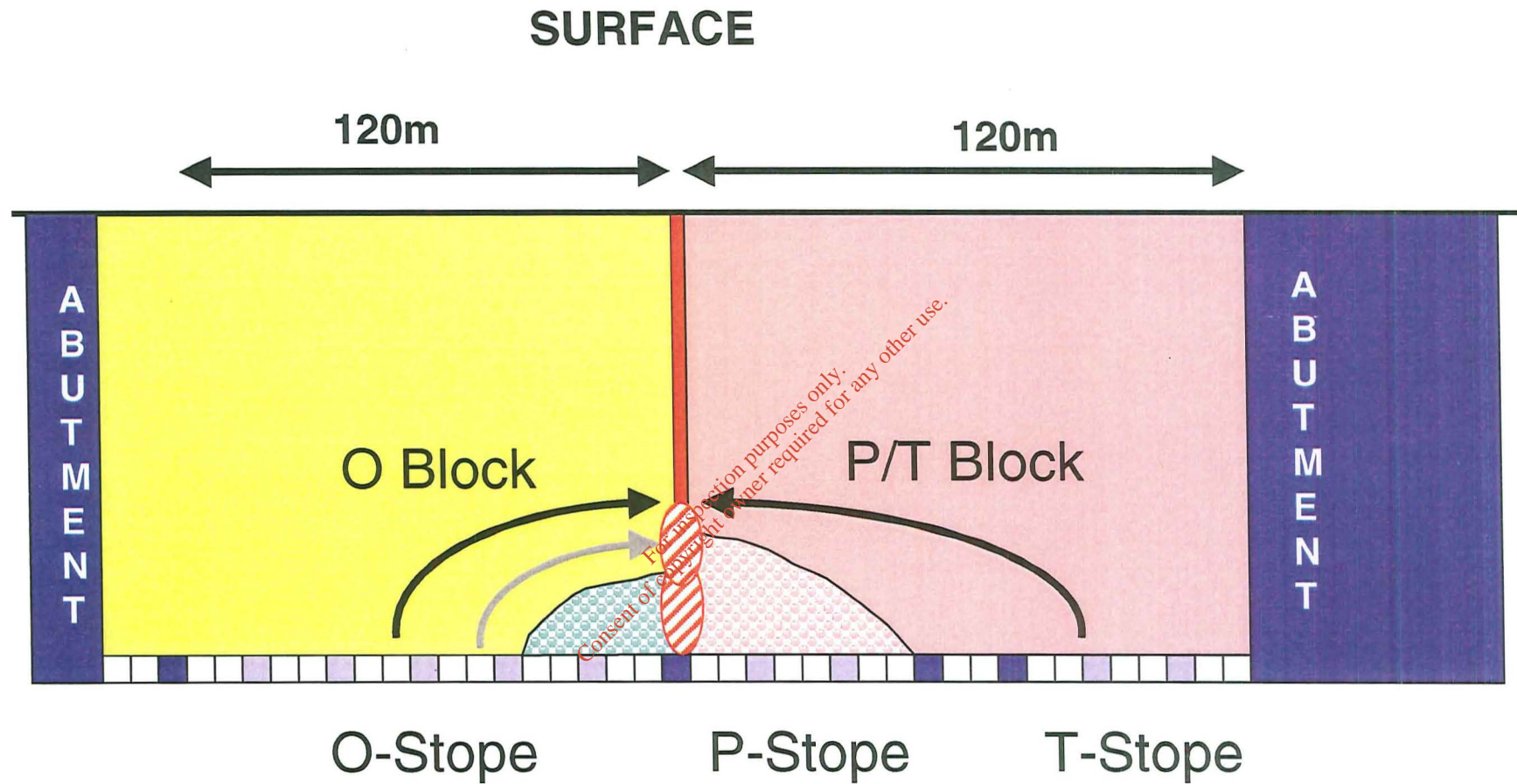


Figure 9. iii) Lateral and vertical extension of initial collapse across whole of P-Stoppe, with stress redistribution to T-Stoppe.

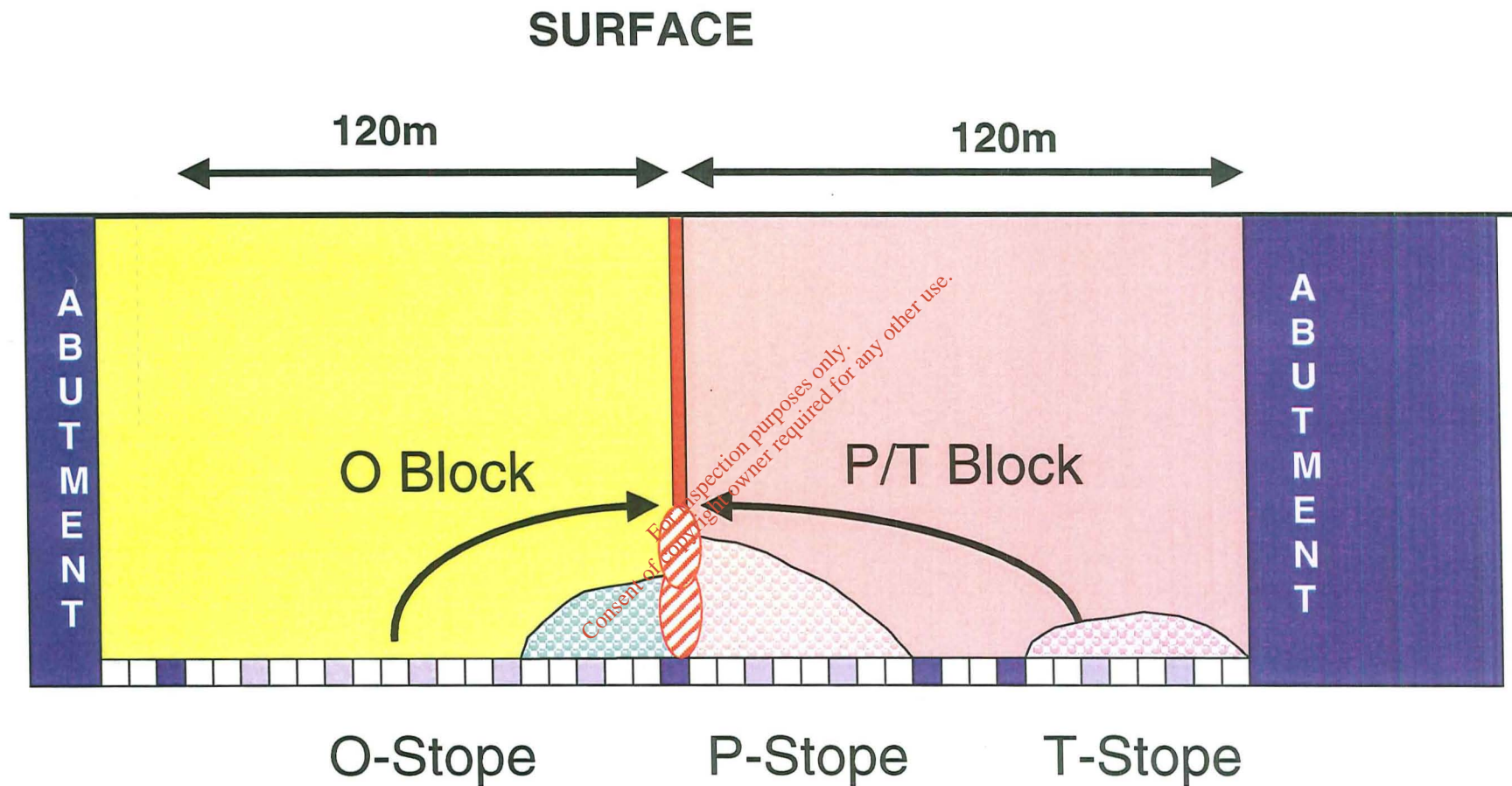


Figure 9. iv) Collapse in T-Stoppe caused by redistributed stresses applied to extremely poor roof conditions.

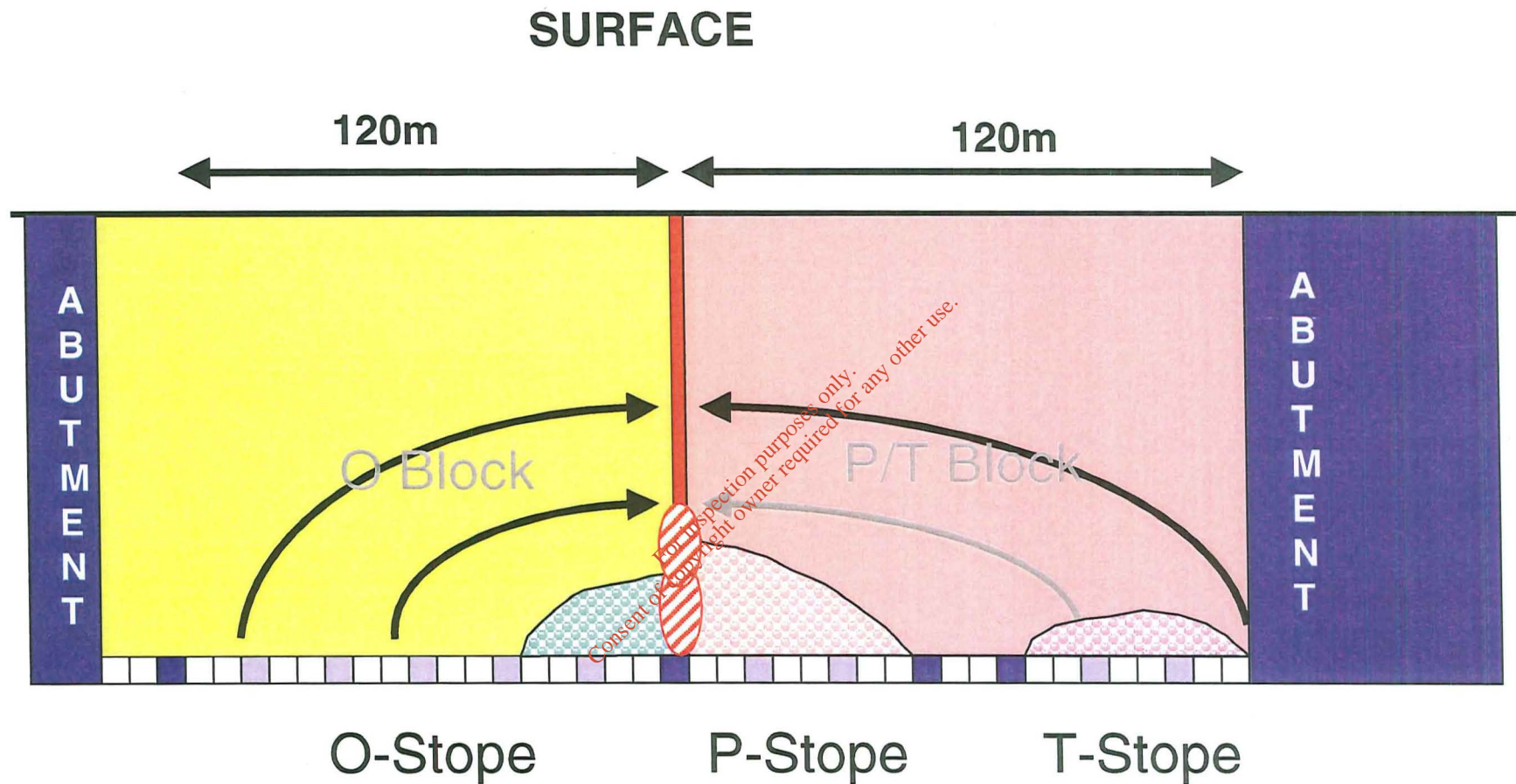


Figure 9. v) Redistribution of stresses to abutment after collapse of T-Stope and arching across to south part of O-Stope.

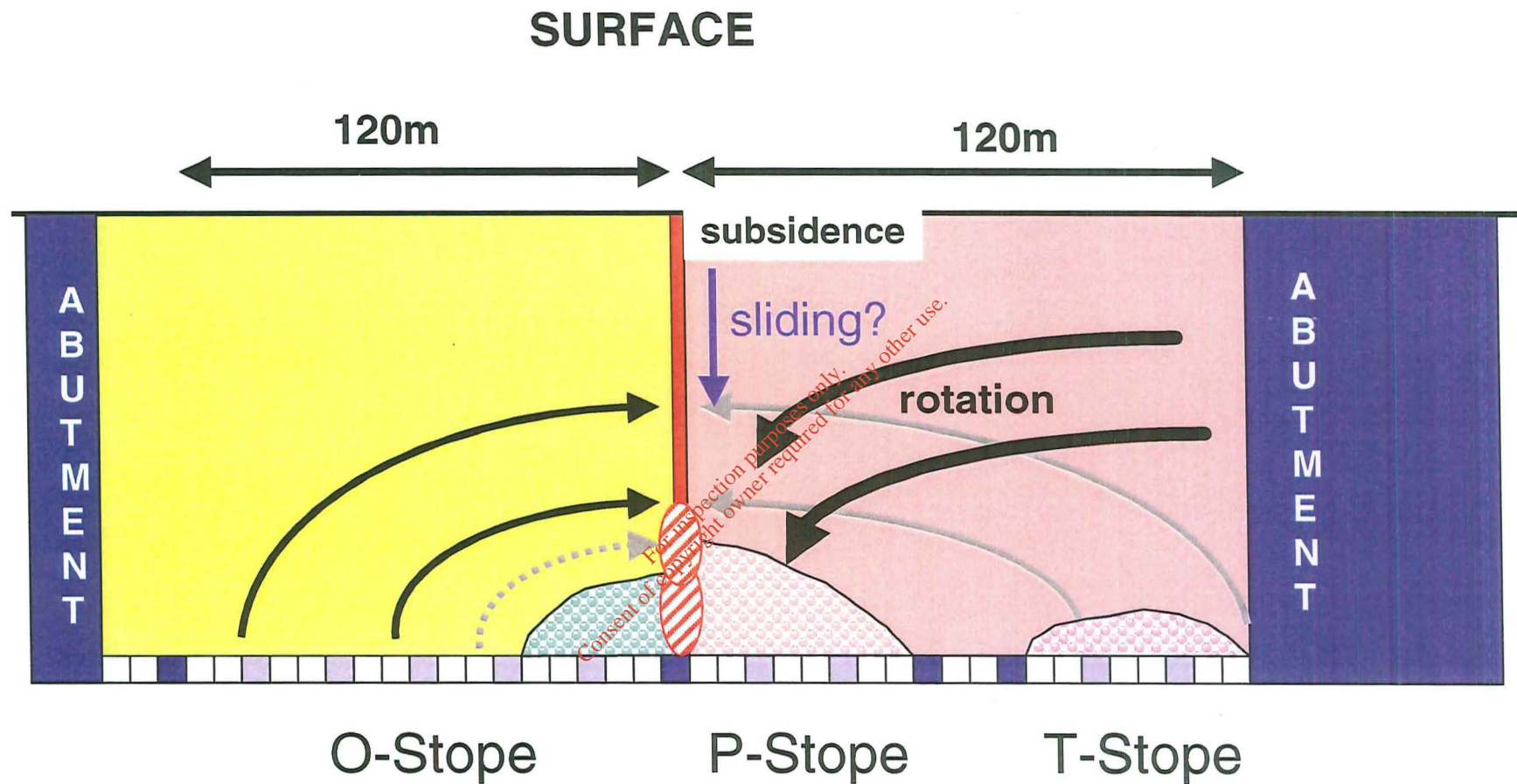


Figure 9. vii) Rotation of P Block causes subsidence on surface at LP127 of 84mm (August 2001) and possibly sliding down the Main Fissure.

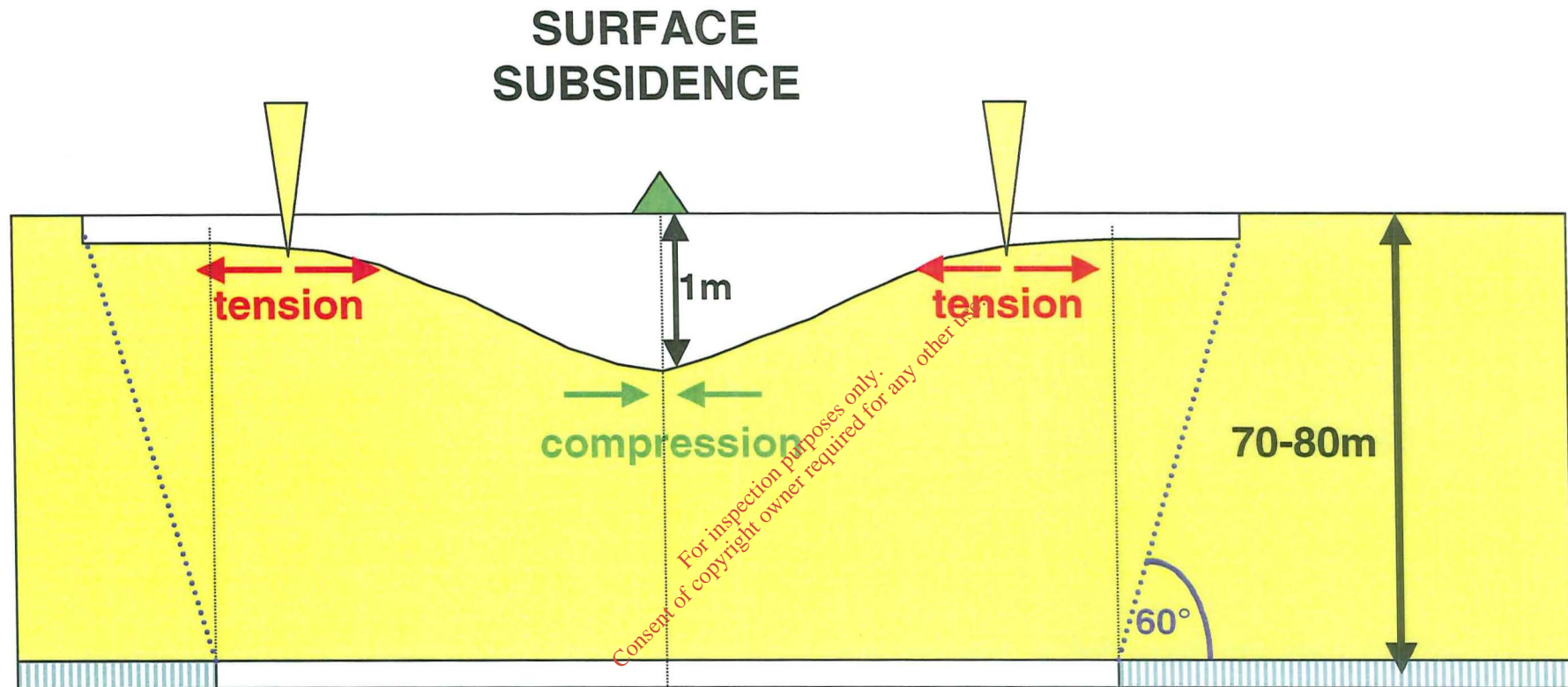


Figure 10. i) Schematic of general shape of subsidence above an underground void, showing location of tension cracks, compression zone and angle of influence.

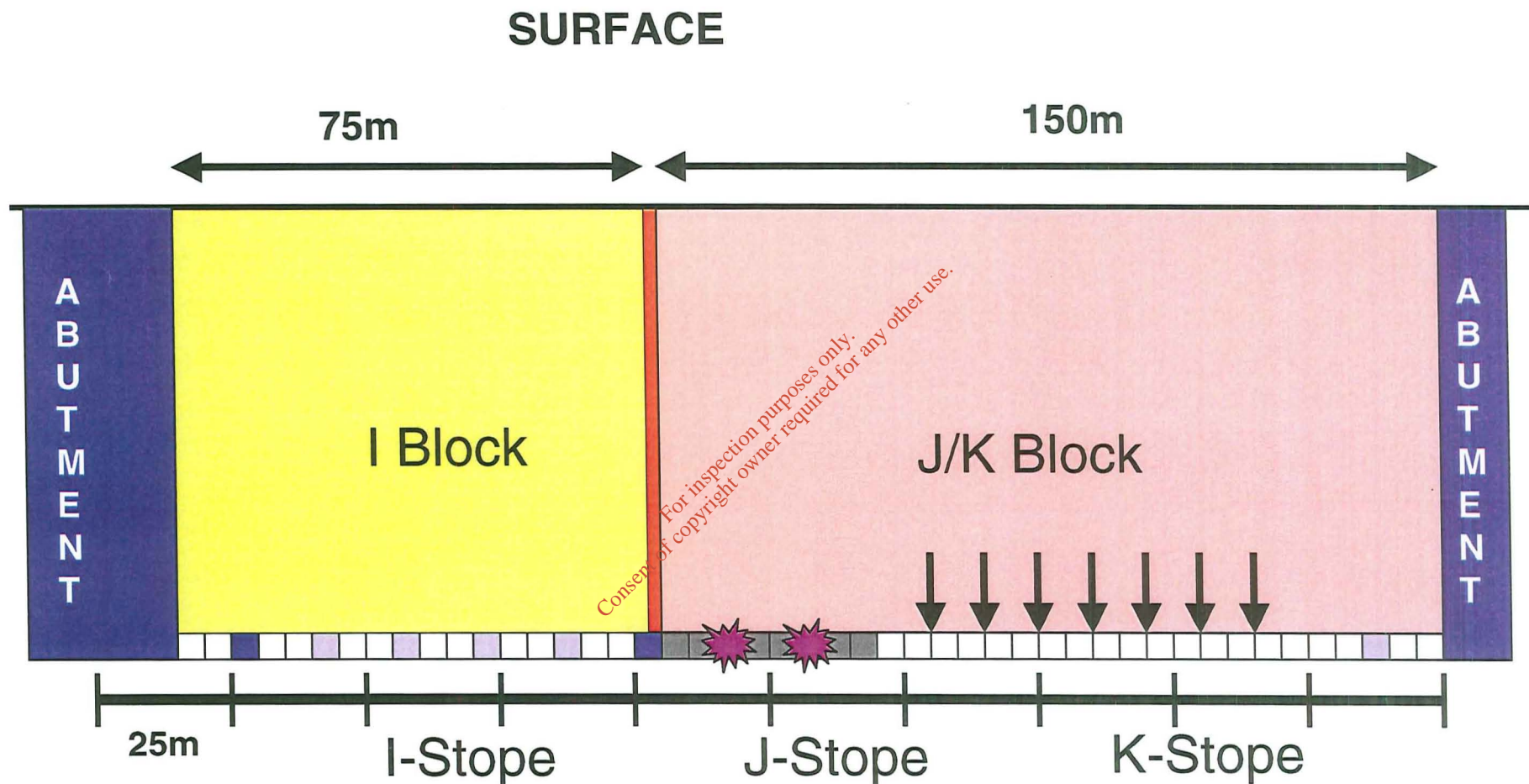


Figure 10. iv) Schematic of I/J/K Stopping area, showing collapse in K-Stoppe and further collapse of J-Stoppe pillars.

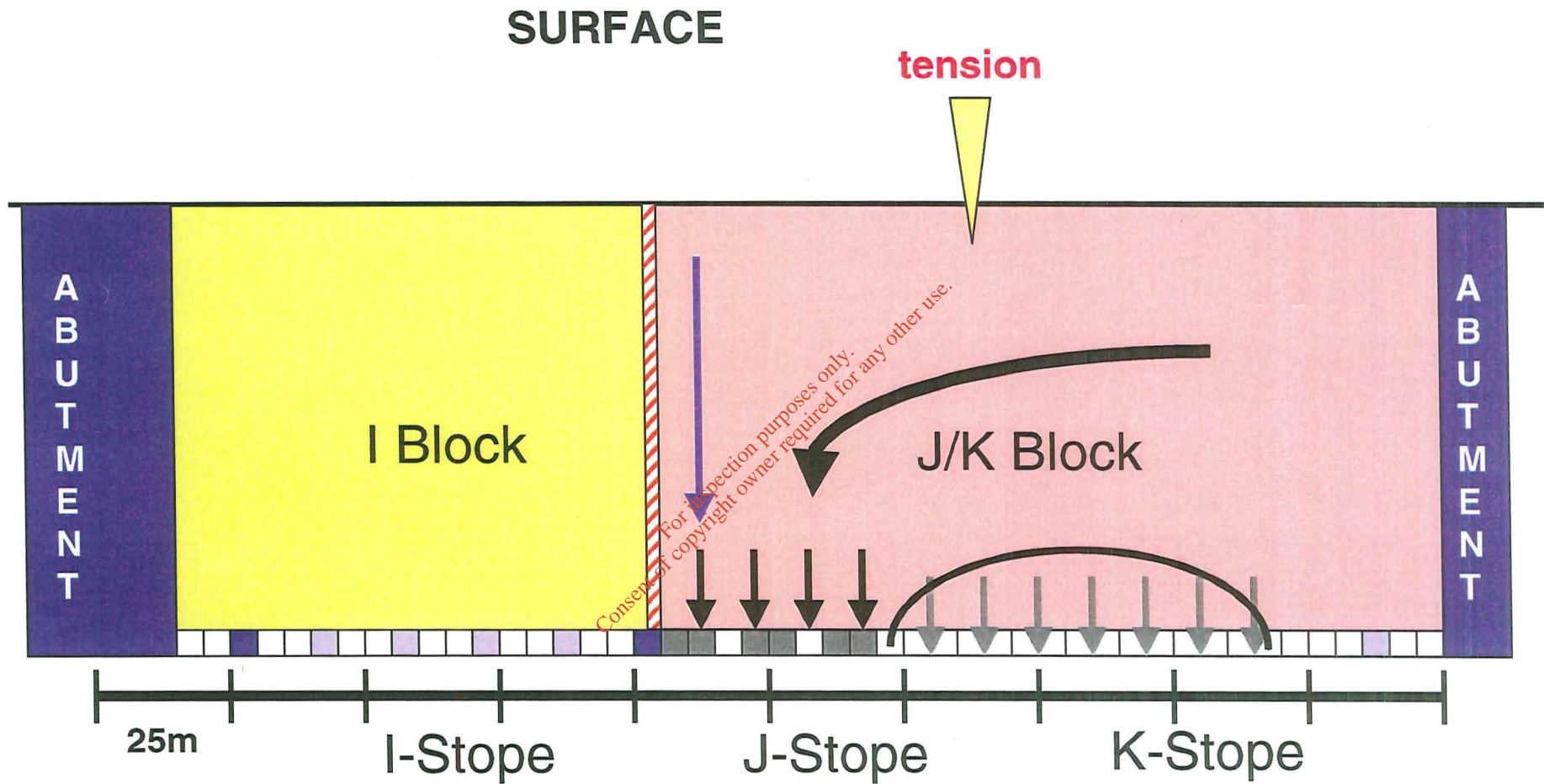


Figure 10. v) Rotation of J/K Block and mobilization of the Main Fissure and tension cracks on surface.

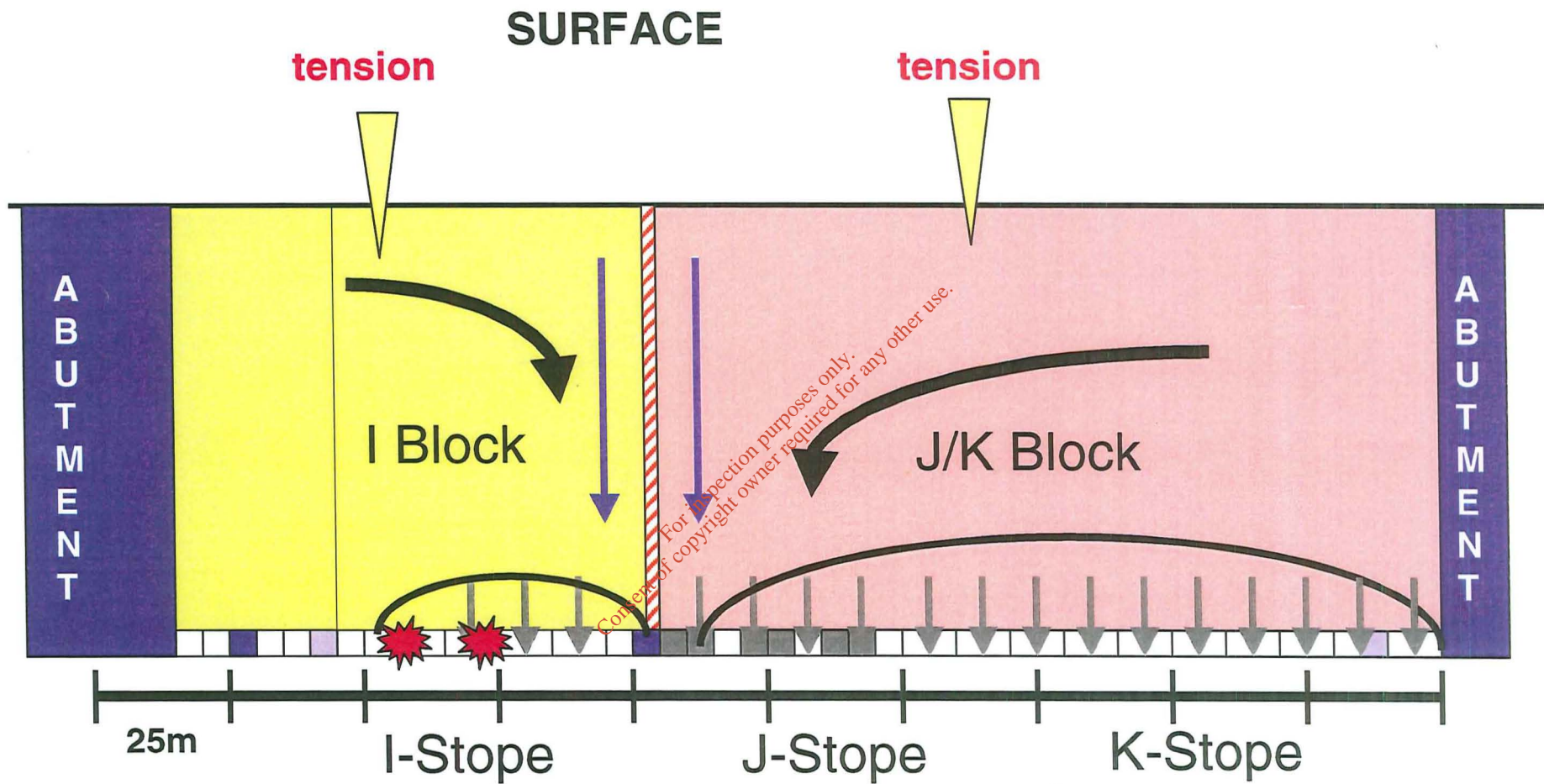


Figure 10. vii) Rotation of I Block results in pillar failure in I-Stoppe and roof falls along G4 Fault.

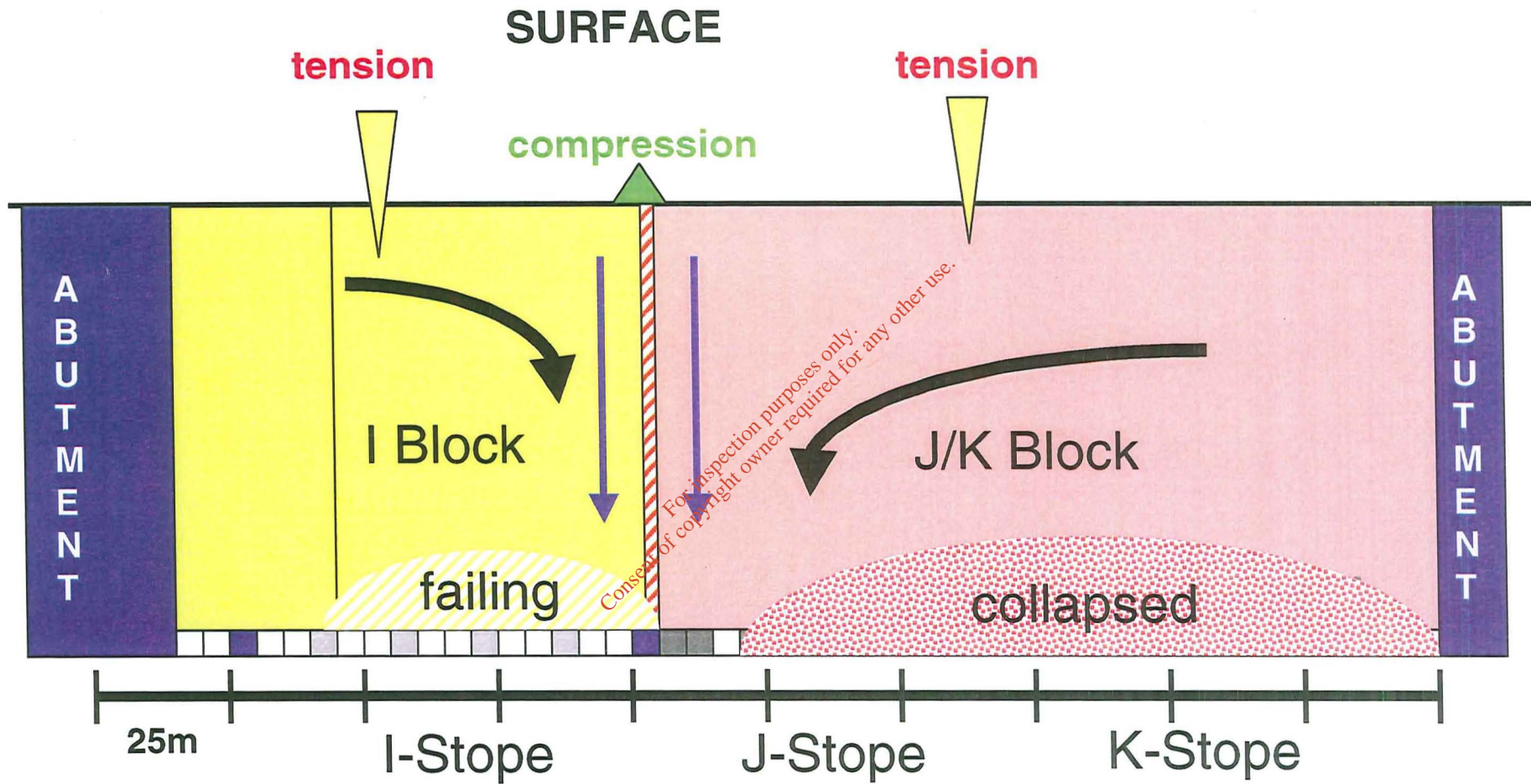


Figure 10.viii) Rotation of I Block and J/K Block causes pressure ridge on surface above Main Fissure.

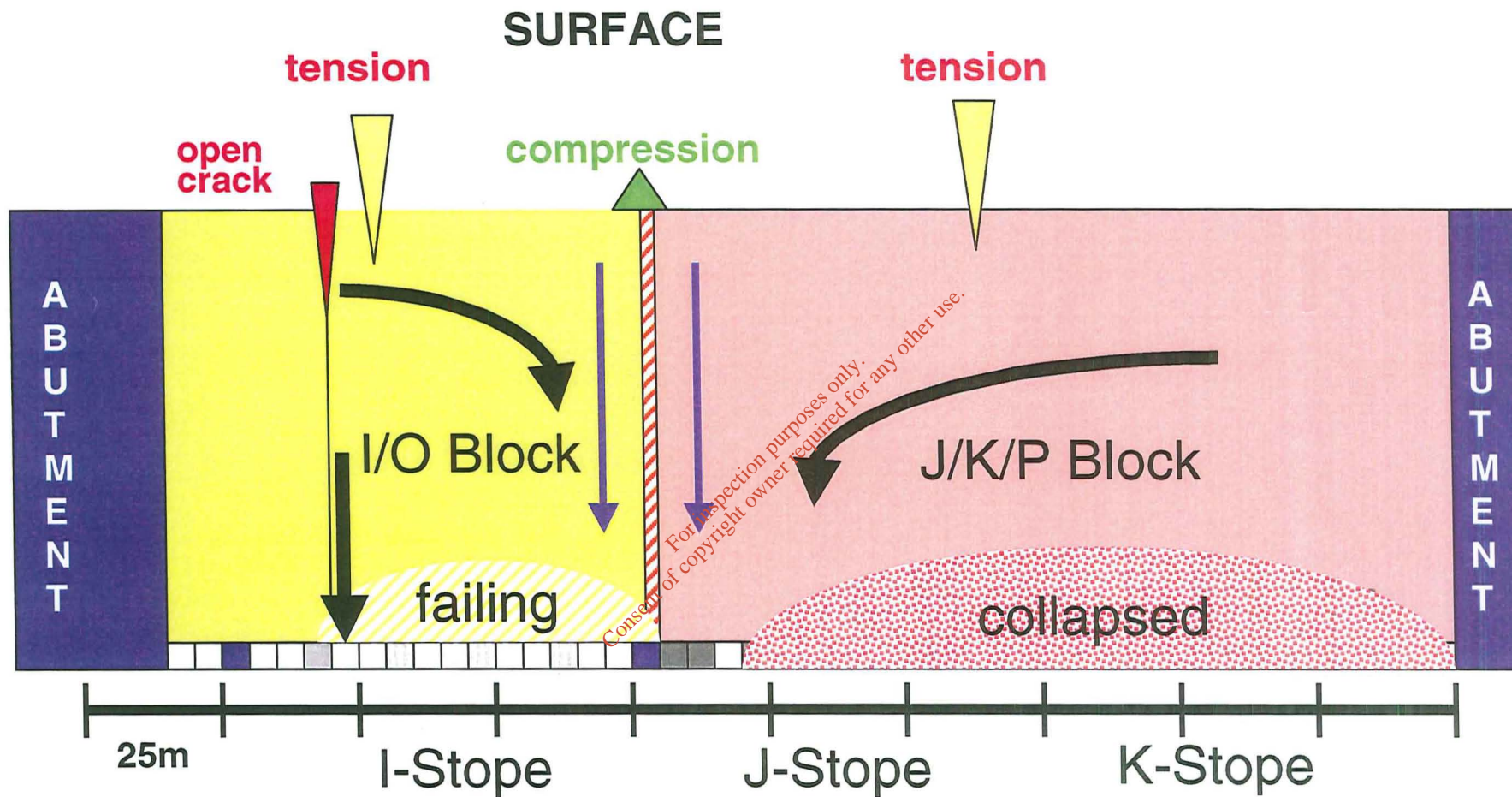


Figure 10. ix) Development of open crack. The J/K/P Block subsides gradually to abutment, but the shorter, stiffer I/O Block cannot and opens a crack along the G4 Fault.

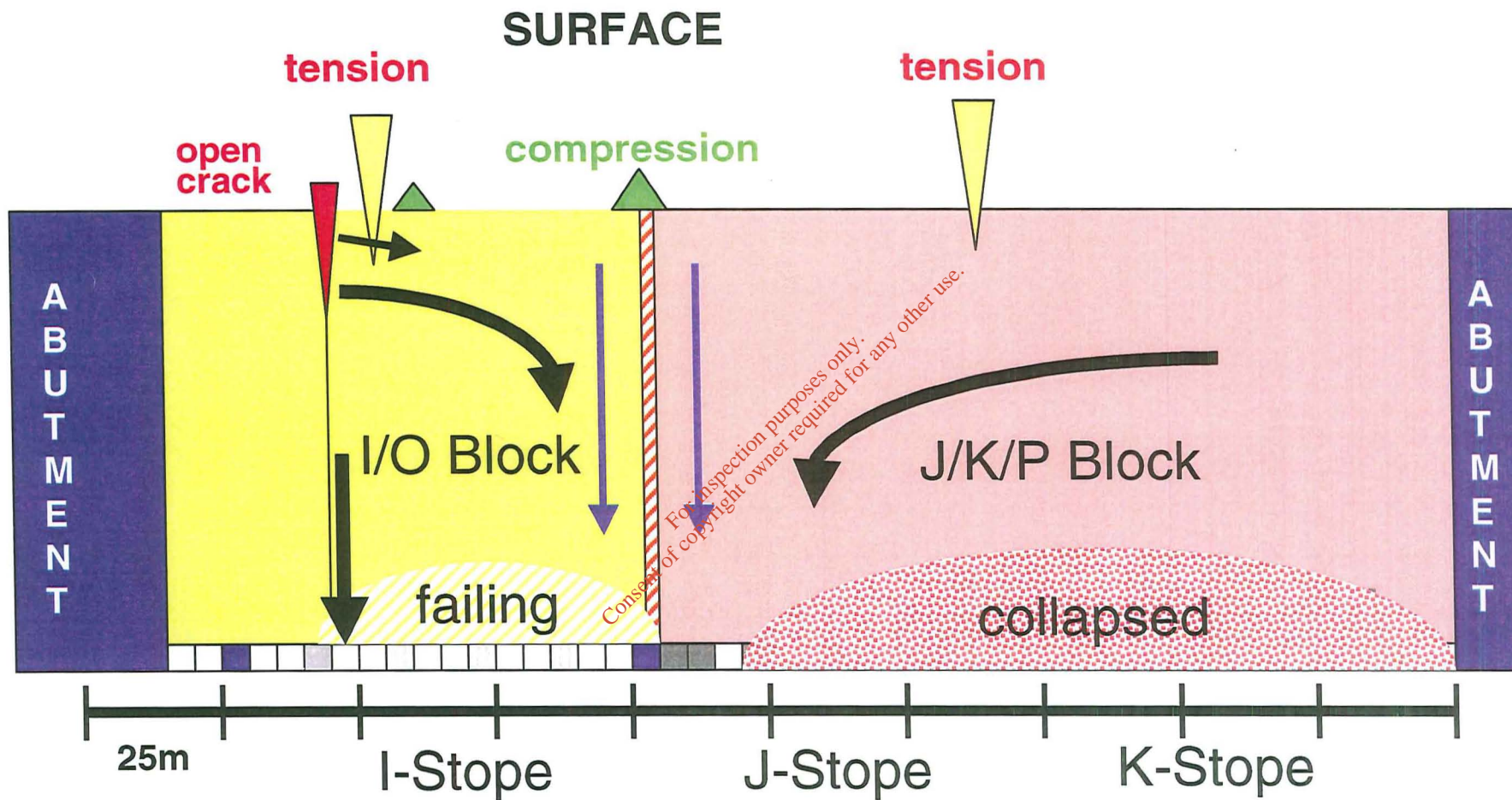


Figure 10. x) As the open crack allows the I/O Block to drop, it re-converges with the other part of the block and causes a small convergence ridge at the top of the hill.

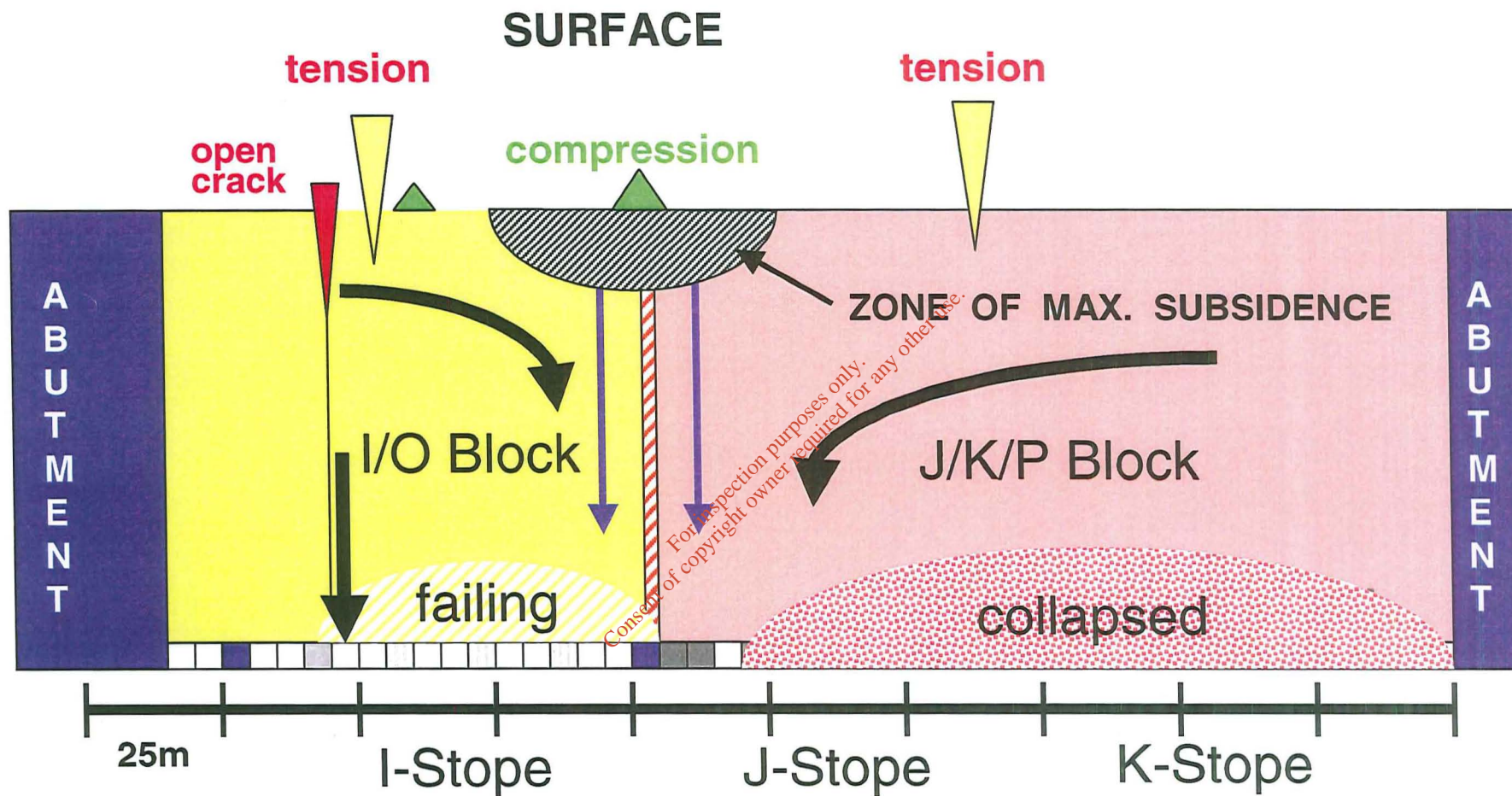


Figure 10. xi) Continued rotation of the I/O Block increases the height of the pressure ridge at the bottom of the hill, which is also the area of greatest subsidence.

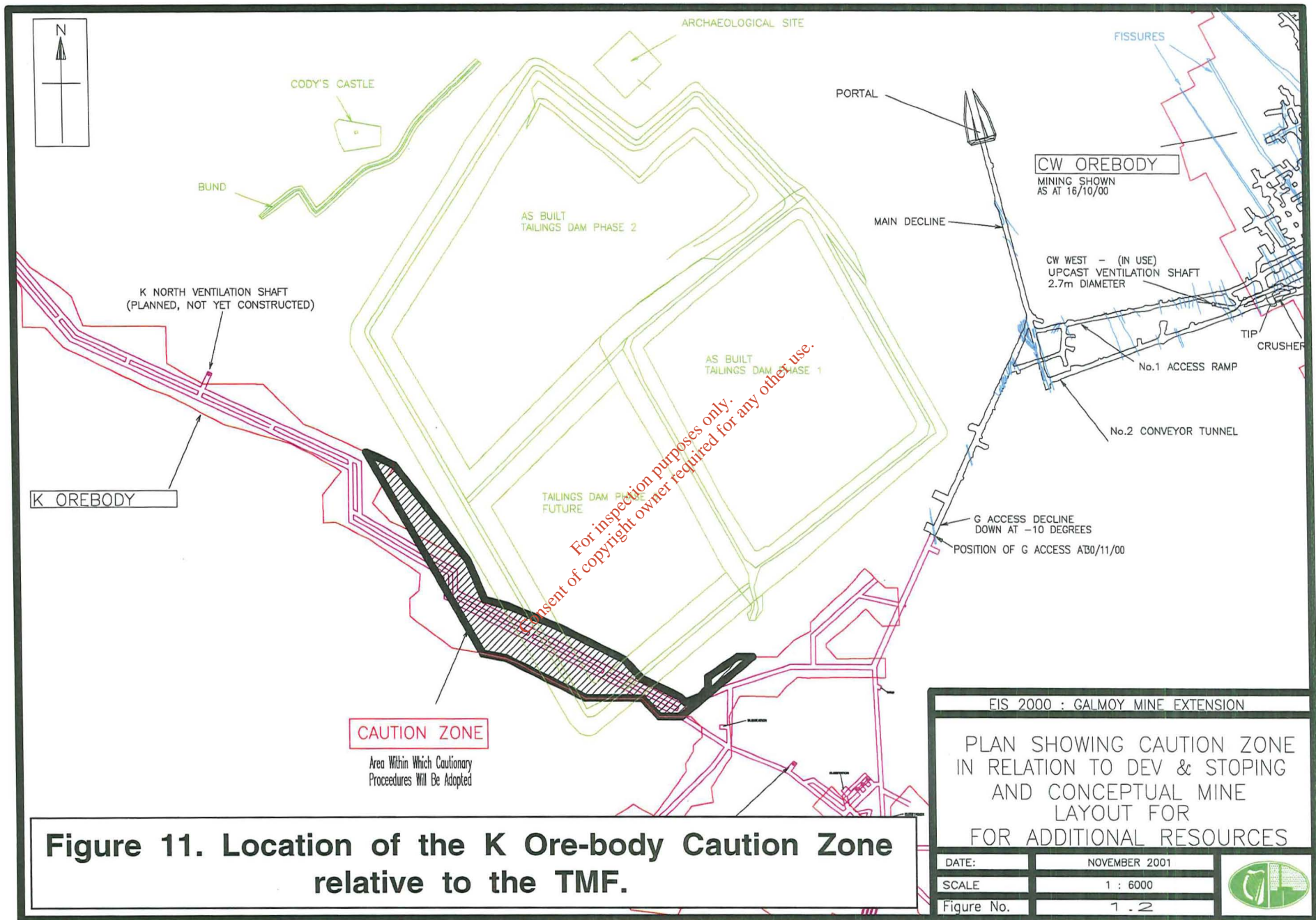


Figure 11. Location of the K Ore-body Caution Zone relative to the TMF.

EIS 2000 : GALMOY MINE EXTENSION	
PLAN SHOWING CAUTION ZONE IN RELATION TO DEV & STOPING AND CONCEPTUAL MINE LAYOUT FOR ADDITIONAL RESOURCES	
DATE:	NOVEMBER 2001
SCALE	1 : 6000
Figure No.	1 - 2

**ZONE OF INFLUENCE
OF SUBSIDENCE**
Initial radius 90m
Final radius 140m

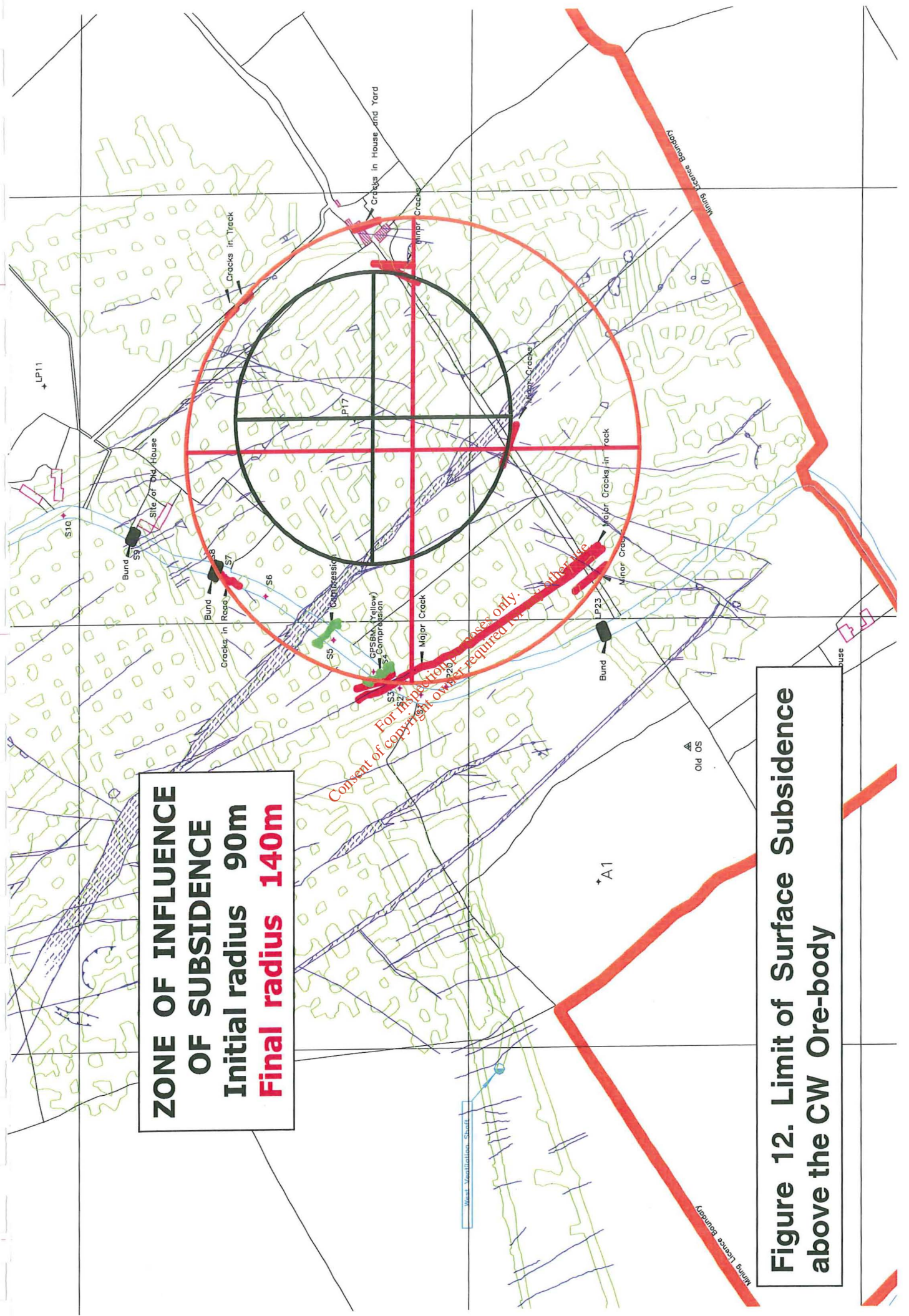


Figure 12. Limit of Surface Subsidence above the CW Ore-body

PHOTOGRAPHS

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Photo 1. Damage to Whiteswall Road showing the open crack (top), the tension cracks (middle) and the pressure ridge (foreground).



Photo 2. Vertical displacement on the open crack at the top of the hill, with the Galmoy facility in the background.



Photo 3. Tension cracks at the north end of the closed section of the road.

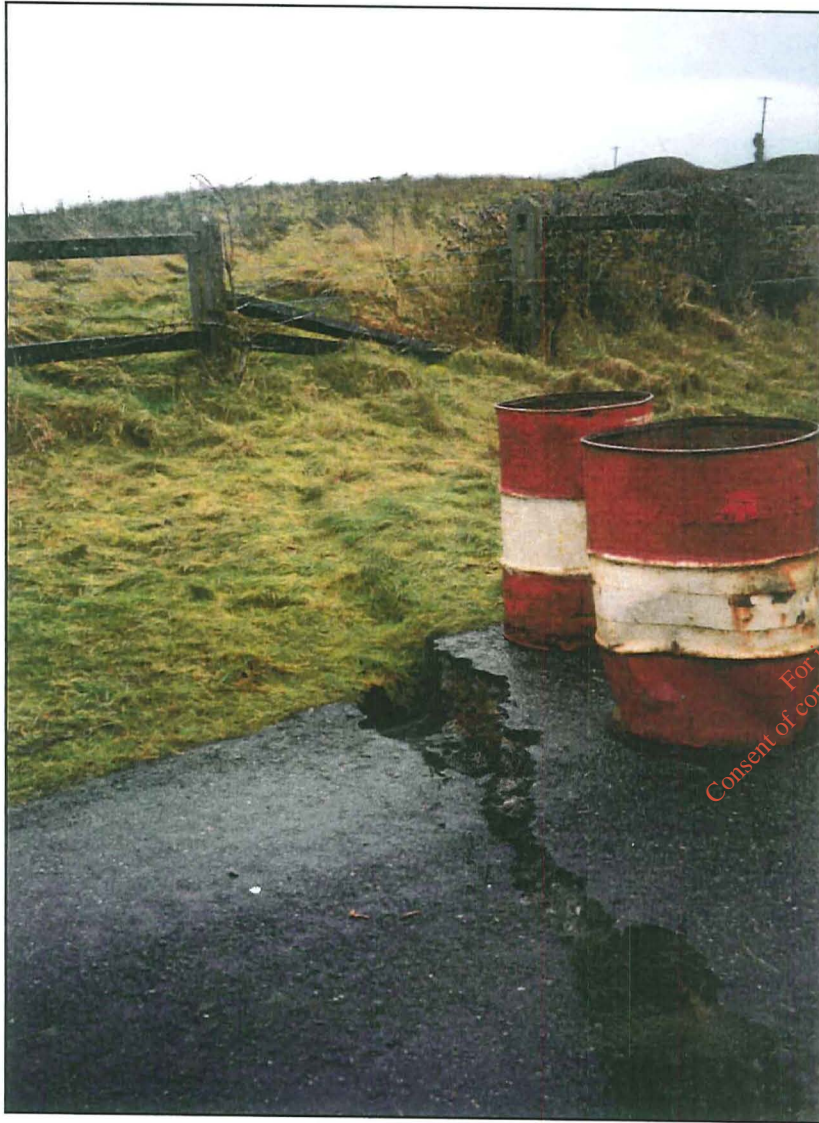


Photo 4. The open crack looking southeast.



Photo 5. The open crack in the forested field, south-east of the road.

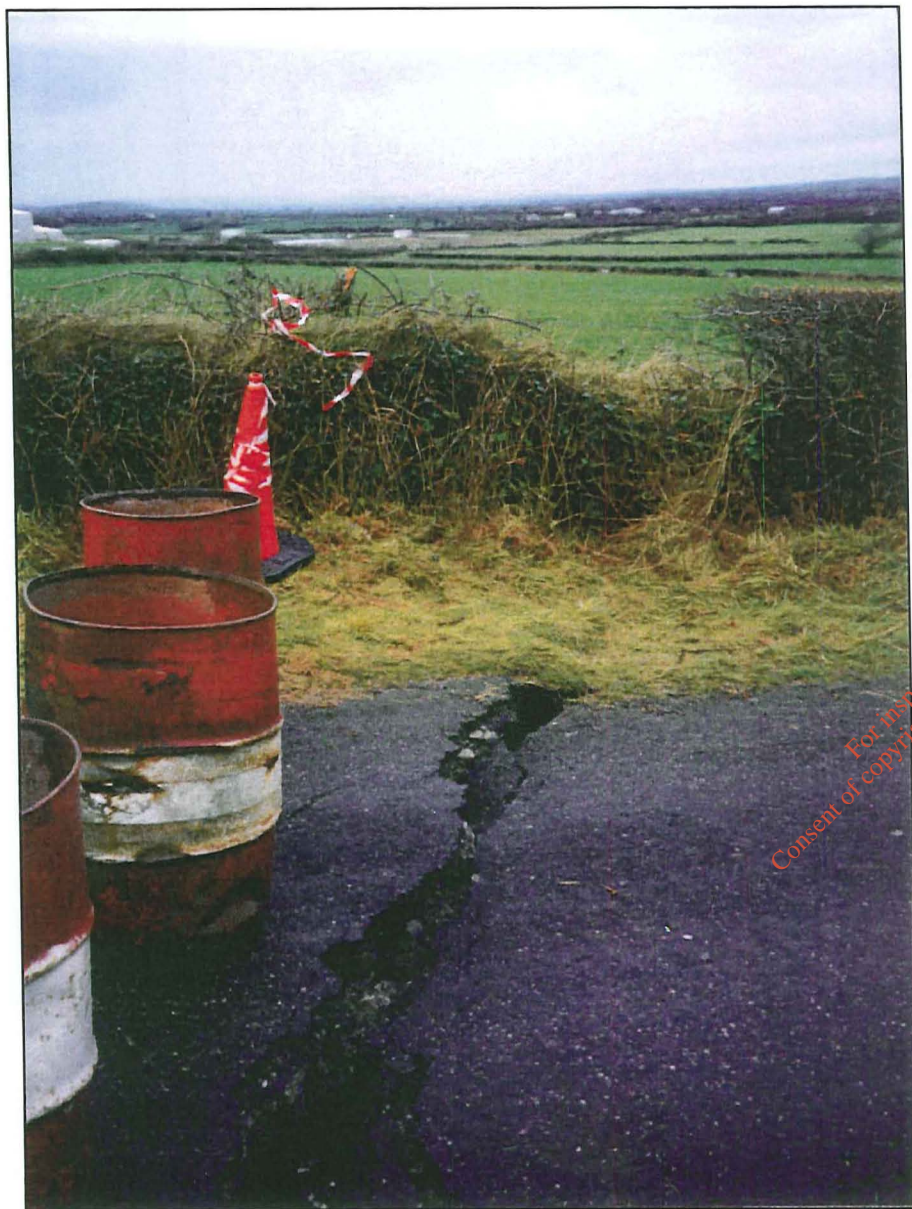


Photo 6. The open crack looking north-west.



Photo 7. The north-westward extension of the open crack in the adjacent field.



Photo 8. The northern extension of the open crack in the north-west field.

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Photo 9. The central pressure ridge at the bottom of the hill, looking south, in early February.



Photo 10. The cracked axis of the central pressure ridge, looking north, in early March.