FAILURE BY OVERTURNING IN GROUND ADJACENT TO CAVE MINING AT HAVELOCK MINE

LA RUPTURE ÉTAIT RESULTÉE DE L'INCLINAISON PRÉS D'UN ÈBOULEMENT À LA MINE DE HAVELOCK

DER BRUCH WURDE VERURSACHT DURCH DIE ERDVERSCHIEBUNG NEBEN EINEM EINSTURZ IN DER HAVELOCK MINE

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SUMMARY A spectacular semicircular subsidence zone has developed in the hangingwall adjacent to caved ground at Havelock Mine in Swaziland. This zone has a radius of 180m, an angle of break of 47½° and subsidence of up to 20m. It is considered to have resulted from tilting of the steeply dipping hangingwall measures towards the mining operation. In tilting, shearing has taken place on the weakest structures in the hangingwall rocks which also dip steeply away from the mining operation. The directions and amount of movement recorded within the subsidence zone indicates the substantial depth of the subsidence zone.

RÉSUMÉ Un tassement de terrain semi-circulaire plutôt spectaculaire s'est produit dans la couche supérieure près d'un éboulement à la mine de Havelock au Swaziland. Cette zone a un radius de 180 mètres, un angle de rupture de 47½° et des éboulements aussi élevés qu'une vingtaine de mètres. On peut considérer ceci comme un résultat de la forte inclinaison de la couche supérieure vers les travaux d'extraction. Par l'inclinaison, un glissement de la partie la plus faible de la pendante qui penche fortement en direction opposée des travaux miniers, s'est produit. Les directions et le nombre de mouvements établis dans la zone d'éboulement indiquent une profondeur importante de la zone d'affaissement.

ZUSAMMEN FASSUNG Ein spektakuläres halbkreisförmiges Versenkungsgebiet hat sich in der hängenden Schicht neben einem Einsturz bei der Havelock Mine in Swaziland entwickelt. Dieses Gebiet hat einen Radius von 180 Meter, einen Bruckwindel von 47½° und Einstürze bis zu 20 Meter teif Man kann annehmen, dass dies eine Folge der starken Neigung zur Seite des Abbaugebietes ist. Durch die Neigung sind Verschiebungen in den schwächsten Lagen der hängenden Schicht vorgekommen, welche stark von der Gewinnungszone wegneigen. Die registrierten Richtungen und Bewegungen in der hängenden Schicht lassen auf eine grosse Tiefe des Einsturzgebietes schliessen.

INTRODUCTION

The surface subsidence zones resulting from block caving operations are rarely confined to within the vertical limits of the undercut area, but commonly extend beyond these limits. An understanding of the mechanism which may be involved in subsidence is a prerequisite to any attempt at assessing the extent of the subsidence zone a caving operation will produce. These assessments are frequently required to ensure that the subsidence does not affect surface facilities or intercept a river or slimes dam. In many cases, the techniques developed for open pit stability analysis can be adapted to this purpose if due regard is given to the effects of the broken ground. The greatest effort in pit slope analysis has been directed to developing techniques for analysing one or other form of gravitational sliding on plane or rational shear surfaces involving "unfavourably" orientated planes of weakness such as continuous or discontinuous joints, bedding planes, slips, faults and shears dipping towards the pit. In most cases little notice is taken of "favourably" orientated planes except insofar as these might link one "unfavourably" orientated plane with another. The example discussed here involved failure on "favourably" orientated planes, and it is hoped that this example will serve to focus some attention on the effect these can have on the stability of block caving as well as in open pits.

THE HANGINGWALL FAILURE AT HAVELOCK MINE

Havelock Mine is situated on the North Western border of Swaziland. The orebody occupies the central portion of a serpentinite sill which with the overlying Fig Tree Series rocks dips to the south at 55°. The orebody and adjacent serpentinite are cut by several major weak shear zones and numerous minor slips. The major features are largely parallel to the orebody or cut across it at small angles. Many of these contain gouge and brecciated material and some are weathered to great depths. The sheared and partly talcified hangingwall portion of the sill is overlain by between 100 and 150m of sediments containing banded cherts, talcose, chloritic and siliceous schists. These rocks are jointed with two sets of short north dipping joints which end at bedding planes or changes in lithology. The joints are straight but rarely contain any filling material. These rocks are also cut by shears which largely parallel the bedding planes. Some of the shears contain narrow gouge fillings and a few others contain graphite. Another serpentinite sill of variable thickness overlies these sediments and in places it has been altered to talc schist and talc carbonate rock. Although little is known of the structures in this sill it is probably safe to assume that it is also cut by south dipping shears. A 20 - 60m thick zone of chloritic sediments and cherts followed by a wide zone of carbonated and siliceous schists overlies this serpentinite.

Longhole shrinkage stoping is the main mining method employed on the mine. The ore is drawn through drawpoints located on the footwall and on horizontal grizzly horizons sited at approximately 45m vertical intervals. The hangingwall caves readily and no large cavities are developed in stopes. Recently, sub level caving has been applied on the lower working levels. In this part of the mine, the direction of retreat is from east to west. Cracks on the hill slope on the hangingwall side of the orebody were first recorded in 1952, and in 1956 a collapse of the hangingwall was recorded. Between October and December, 1962, cracks developed over a large semicicular area, 180m in radius, and centred above the south western limit of mining.

Early in 1966 there was a 60 to 90m wide extension of this zone on the south western side. In each case failure occurred after mining had progressed along strike 140 - 150m. The angle of break (the dip of the line joining southern extremity of cracks to the southern limit of mining) in 1952 was 42°, in 1962 it was 47° and in 1966, 47½°. No angle was recorded in 1956. The 1962 and 1966 failures were preceded in each case by pressure and heavy damage to prebreaking and grizzly drifts. Despite a considerable extension of the mined out area since 1966 there has been no significant extension of the hangingwall subsidence zone.

DESCRIPTION OF THE SUBSIDENCE ZONE

The subsidence zone which developed from the 1962 cracks was roughly semicircular in shape with a radius of 180m. The largest subsidence occurred in the south eastern sector of the subsidence zone, where there is a north facing peripheral scarp. This scarp was 10m high in 1965 and 1972 was almost 20m in height. A narrow zone of tensile cracks lies beyond this scarp. In the central portion little or no subsidence occurred and no peripheral scarps developed. In the northern portion along the previous caving limit, subsidences of up to 7m occurred between 1962 and 1965, and on the eastern and western ends, small peripheral scarps developed.

Within the subsidence zone there was a general tilting of large blocks of ground northwards which exposed the southern edges of these blocks, and which appear as a series of scarps when viewed from the south. These scarps first appeared as east-west cracks up to 160m long. With tilting, the heights of the scarps increased, to as much as 6m. This zone was monitored by a line of survey beacons which was established after the appearance of the first cracks. These were surveyed over a period of three years, and the amounts of movement recorded varied from less than 1m in the south to 7m in the north. The direction the pegs moved in was at right angles to the orebody and on average moved down at an angle of 31°, which was steeper than the 20° slope on which they were located. On five of the six large blocks which had two or more pegs located on them, the northern pegs moved at a steeper angle than the southern pegs, the difference varying between 2° and 6°, with an average of 4°. On the sixth the difference was negligible. Assuming that these blocks were simply integral slabs each tilting on its own fulcrum, the fulcrums would be at about 120m in depth and 60m to the south of the surface positions.

In addition several lines of survey pegs were established extending from the limits of cracking in 1962 for several hundred metres into the hangingwall. These were not surveyed again after the initial survey until after the extensions to the subsidence zone in 1966, and since then these have been resurveyed at regular intervals. Within the 1966 subsidence zone the movements recorded on these pegs were similar to those previously recorded by the survey beacons. Beyond the limit of cracks, small movements were recorded on the survey pegs but the greater proportion occurred prior to the first survey done after the cracks were noticed.

The physical appearance of the ground within the subsidence zone was the same as the previous one with northward tilting of blocks. Since 1966 there has been no extension of the cracks, but large subsidences have occurred along the western perimeter. In the original subsidence zone extensive erosion has taken place, in places giving the appearance of a mud flow.

After the cracking of 1966, it was decided to investigate the hangingwall zone from a drift driven into the hangingwall at an elevation of 1 005m (see Figure 1) with crosscuts driven northward to intersect the subsidence zone. This development was completed at the end of 1967. The angle of caving indicated by the intersections of caved ground was approximately 70° - very different from the 47° angle of break. Boreholes drilled upwards and northwards to detect movements which would indicate the bottom of the failure zone were tested with go-no go gauges. These did not show any evidence of movement on north dipping joints. The wire extensometers and water levelling devices located in the crosscuts recorded small movements of the order of millimetres as the pre-breaking face approached and passed the crosscut lines to the north. Small movements on shear planes were visible in the drive and crosscuts. These fell into two classes - lateral movements on near vertical east west slips, and normal-fault type movements on shears dipping away from the orebody. Typical of these was one shear dipping at 67° south with 2mm dilation and 10mm normal movement.

A series of stress measurements, done by the overcored photo-elastic disc technique, indicated that the major principal stress of approximately 12 MPa was normal to the plane of the orebody. The intermediate principal stress of about 7,5 MPa and minor principal stress of about 3 MPa dipped in the plane of the orebody eastwards and shallowly westwards respectively.

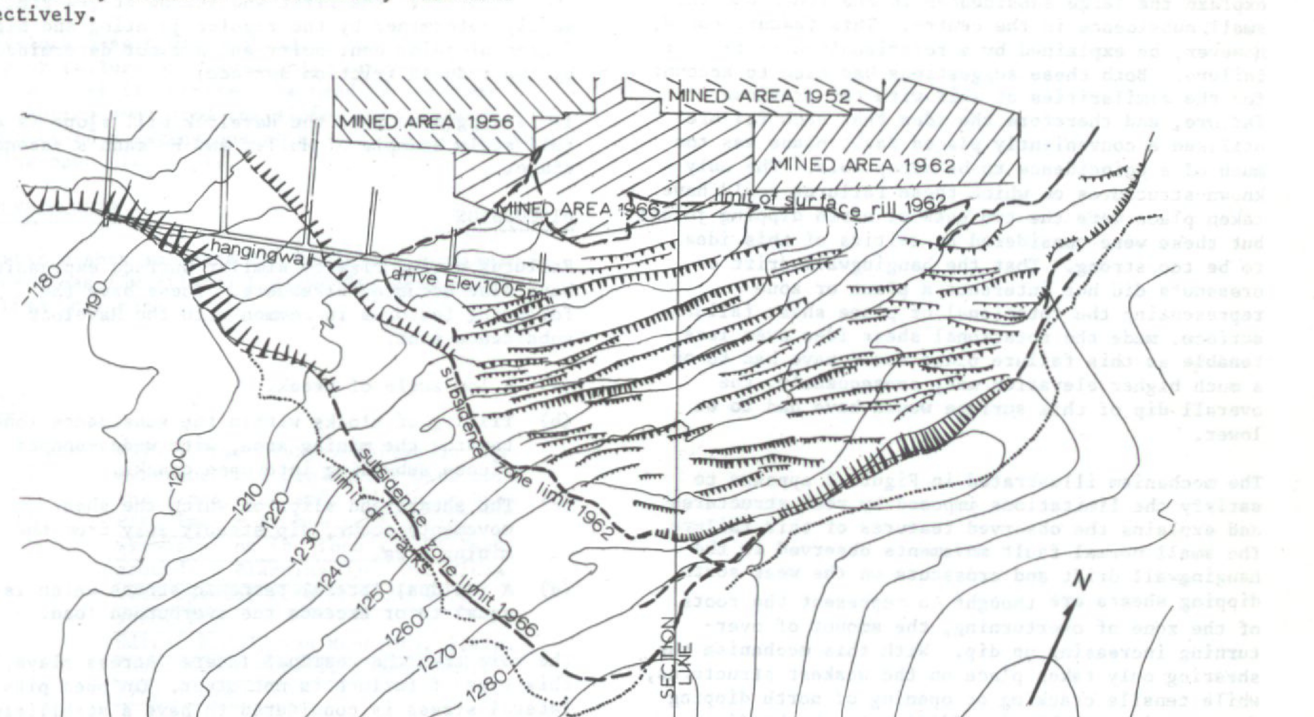

FIG 1 HAVELOCK MINE HANGINGWALL SUBSIDENCE ZONE
Cracks within subsidence zone as surveyed in October 1965

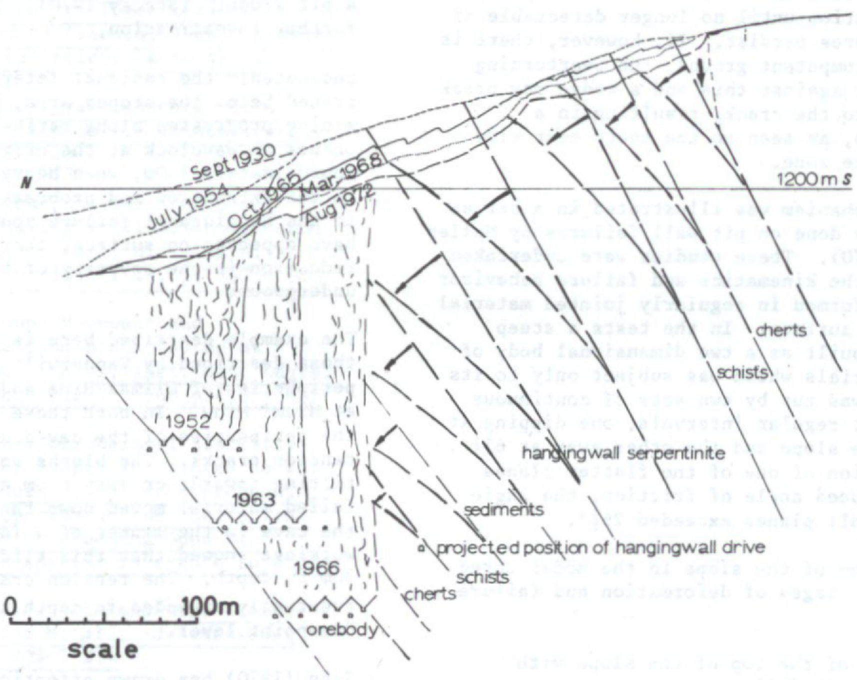

FIG 2 SECTION THROUGH THE HAVELOCK SUBSIDENCE ZONE
Illustrating the development of the subsidence zone by tilting towards the mining.

INTERPRETATION OF FAILURE MECHANISM

Plane shearing was one of the earliest mechanisms suggested for the 1962 failure. This could not explain the large subsidences in the south and the small subsidence in the centre. This feature could, however, be explained by a rotational shear from of failure. Both these suggestions had also to account for the similarities of this with the previous failure, and therefore the idea that each failure utilised a conveniently placed fault plane was too much of a coincidence to be acceptable. The only known structures on which these failures could have taken place were the two sets of north dipping joints but these were considered by critics of this idea to be too strong. That the hangingwall drift or crosscuts did not intersect a plane or zone representing the rotational or plane shear failure surface, made the rotational shear idea even less tenable as this failure plane would have had to be a much higher elevation and, consequently, the overall dip of this surface would have had to be lower.

The mechanism illustrated in Figure 2 appears to satisfy the limitations imposed by rock structures and explains the observed features of this failure. The small normal fault movements observed in the hangingwall drift and crosscuts on the weak south dipping shears are thought to represent the roots of the zone of overturning, the amount of overturning increasing up dip. With this mechanism the shearing only takes place on the weakest structures, while tensile cracking or opening of north dipping features is probable in addition to the bending strains each slab would be subject to. On surface the lateral displacement would be greatest close to the mining operation and would decrease away from the mining operation until no longer detectable if the weak structures persist. If, however, there is a zone of more competent ground, the overturning may end abruptly against this and a wedge may break off and fall into the crack, resulting in a peripheral scarp, as seen on the south east side of the subsidence zone.

This failure mechanism was illustrated in a series of model studies done on pit wall failures by Muller and Hofmann (1970). These studies were undertaken to investigate the kinematics and failure behaviour of rock slopes formed in regularly jointed material having one slip surface. In the tests a steep rock slope was built as a two dimensional body of equivalent materials which was subject only to its own weight and was cut by two sets of continuous joints spaced at regular intervals, one dipping at 26½° towards the slope and the other away at 63½°. With the exception of one of the flatter planes which had a reduced angle of friction, the angle of friction on all planes exceeded 26½°.

During excavation of the slope in the model three main successive stages of deformation and failure were noted :-

(1) overturning of the top of the slope with subsequent rock falls,

(2) far reaching deformations ending with failure of the slope front and

(3) sliding of the slope rock after excavations had reached the reduced friction surface, after which large deformations of the slope led to the collapse of the greater part of the potential sliding mass.

They state that the first and second stages are mainly determined by the regular jointing and high degree of joint continuity and are not determined by the reduced friction surface.

It is suggested that the Havelock hill slope is a full scale example of Muller and Hofmann's second stage.

DISCUSSION

Failures giving rise to similar surface expressions have also occurred elsewhere. These have the following features in common with the Havelock subsidence zone.

(a) A low angle of break.

(b) Tilting of blocks within the subsidence zone towards the mining area, with wedge-shaped pieces subsiding into open cracks.

(c) The shears and slips on which the shear movements occur, dip steeply away from the mining area.

(d) A residual lateral tectonic stress which is equal to or exceeds the overburden load.

The role that the residual lateral stress plays in this type of failure is not clear. In open pits a lateral stress is considered to have a stabilising influence on the pit slopes, but it has also been shown that the lateral stress widens the zone of tensional stresses which occurs behind the crest of a pit slope. (Stacey 1970). This aspect requires further investigation.

Undoubtedly the residual lateral stress is concentrated below the stoped area, and this builds up as mining progresses along strike to a maximum, which occurs at Havelock at the critical strike length of approximately 150m, when heavy damage is experienced in the extraction and prebreak drifts and an extension to the hangingwall failure zone follows. After cracks have appeared on surface, there appears to be a reduction in the severity of the damage experienced underground.

The example described here is somewhat different to those described by Vanderwilt (1946) in the peripheries of Climax Mine and by Fletcher (1959) at Miami Mine. In both these cases the ground in the peripheries of the caved areas was cut by vertical tension cracks. The blocks so formed failed by tilting towards or away from the cave. At Climax the failed material moved down the 30° hill slope towards the cave in the manner of a landslide. Underground workings showed that this sliding zone did not exceed 30m in depth. The tension cracks, however, eventually extended in depth to just above the drawpoint level.

John (1970) has drawn attention to the possibility of this type of failure in the open pit walls and mentions a failure of this type in a highway in Los Angeles Country, California. But in his attempt at analysing the stability of slopes with joints dipping both steeply away and shallowly towards the pit, John has used an over simplified approach based on the slope angle and shapes of the blocks which ignores the joint properties and the normal and shear stress on them.

CONCLUSION

The Havelock hangingwall subsidence zone is an example of failure on "favourably" orientated structures. It illustrates the need to consider planes dipping away from the mining when assessing the effects of a caving operation on surface, or in analysing open pit slopes.

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REFERENCES

Muller L. and Hofmann H. 1970. "Selection, Compilation and Assessment of Geological Data for the Slope Problem". Planning Open Pit Mines - Proceedings of the symposium on the Theoretical Background to Planning Open Pit Mines with special reference to slope stability. Editor P.W.J. van Rensburg. S.Afr. Inst. Min & Metall. Johannesburg 1970 p.153 - 170

Stacey T.R. 1970. "The Stresses surrounding Open Pit Slopes". Planning Open Pit Mines -. Proceedings of the Symposium on the Theoretical Background to Planning Open Pit Mines with special reference to slope stability. Editor P.W.J. van Rensburg. S. Afr. Inst. Min. & Metall. Johannesburg 1970 p.199 - 207

Vanderwilt J.W. 1949. "Ground Movement adjacent to Block Caving at Climax Molybdenum Mine". Amer. Inst. Min. Engrs. Transact. v. 181 1949. p. 350 - 370

Fletcher J.B. 1960 "Ground Movement and Subsidence from Block Caving at Miami Mine". Amer. Inst. Min. Engrs. Transactions v.217 1960 p.413 - 422

John K.W. 1970 "Three Dimensional Stability Analysis of Stopes in Jointed Rock". Planning Open Pit Mines - Proceedings of the Symposium on the Theoretical Background to Planning Open Pit Mines with special reference to slope stability. Editor P.W.J. van Rensburg. S.Afr. Inst. Min. & Metall. Johannesburg 1970. p. 209 - 214