Combating rock bursts in underground excavations

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Abstract

Excavations of tunnels in rock medium are a complicated, risky and expensive process. Excavations cause a large stress gradient and the potential for release of the rock's stored strain energy. The rate of release of the strain energy is important to assess the stability and safety of excavations. A gradual release may be perfectly safe, whereas the sudden and violent release of energy is called rock burst. Rock burst is a kind of dynamic instability caused by the sudden release of strain energy during the brittle fracturing of the surrounding rock mass around underground openings, in which the fragments of fractured rock are projected out. Rock bursts are a major hazard in underground excavations. The severity of damage due to a rock burst often varies greatly over small distances. A detailed understanding of the damage mechanisms, and the application of this knowledge to the design and support of excavations, will help minimise hazards posed by rock burst. Rock bursts have occurred in a variety of excavations including mines. The problems of rock burst in the deep mines of Kolar Gold Field in Karnataka in India, South African deep gold mines and in Head Race Tunnel downstream face of Parbati Hydroelectric project in Himachal Pradesh (India) are discussed in this paper and suitable measures suggested to combat rock burst are highlighted.

1. Introduction:

Rock bursts are violent rock failures that occur in proximity to underground excavations. Rock bursts have long been recognized as a major hazard when mining rock at depth. Such problems of rock bursts have been reported from the mines in Canada, India, South Africa and the United States of America and also from construction of tunnels in hydroelectric projects around the globe.

When excavations are made in underground, significant changes in potentials and strain energies of the rock in their vicinity occur. The potential energy of the mass of rock removed from excavations is increased by an amount equal to the product of the mass of the broken rock, the gravitational acceleration and the depth from which the rock is hoisted. One explanation of for the origin of rock bursts is that they are unstable releases of some of the decrease in potential energy of the rock around the excavations (Cook, N.G.W.1983).

1.1 History of Rock bursting:

In North America, the first rock burst was believed to have occurred at the Atlantic Copper mine in Michigan in 1904-Bolstad (1990) and as early as 1928 in Canada. in the early 1940's in the Sudbury and Kirkland Lake areas of Ontario the rock burst problem was regarded as a serious safety hazard.

Rock bursting was first experienced as a significant but relatively infrequent problem in the Kalgoorlie district in the early part of the last century with a fatality and several injuries attributed directly to a 'severe earth tremor' in 1917 – Potvin and Hudyama

(2001). During the last decade of the country, as the extraction of the deepest massive ore bodies of the Mount Charlotte mine peaked, several very large mining-induced tremors were experienced.

In hard rock mining, most activity appears to have been experienced in the Coeur d'Alene district of Idaho, USA where rock bursts were first reported in 1930, according to Bolstad (1990). According to early records, the first rock burst is reported to have occurred in a slope below 960 ft (300m) in the Oorgaum mine in the year 1899 in Kolar Gold Fields mine in India. The rock burst problem further continued from the beginning of the last century. At shallow depths, these problems were not critical except while mining shaft pillars and in exceptional cases ore shoots which were highly stressed due to justa-position of faults. Buildings on surface with 2-3 km from the epi-central region have been damaged. The magnitude of some major rock burst tremors was in the range of 4.5 to 5.0 on Richter scale. As mining become deeper and more extensive "area rock burst" caused widespread damage to main infrastructure e.g. shafts and deep foot wall haulages as well as to the producing stopes. - Krishnamurthy R. and Gupta P.D,(1983).

In South African Gold mines the very deep and very extensive tabular mining has led to a far more severe and prolonged manifestation of the rock burst hazard than has occurred anywhere else in the world. Rock bursts problems were faced during construction of highway tunnels. The tunnels in Norwegian highway were made along and around the fjords. This has often created rock burst problems due to gravitational valley side stresses - Myrang, A.M. and Grimstad, E.(1983)

Rock bursts problems were faced during excavation of head race Tunnel of Parbati Hydroelectric project in Western Himalayas, Himachal Pradesh, India. From the beginning of 2004 there were continuous rock bursting with loud sound similar to face blast sound resulting in serious injury to workmen, fatal accidents and loss of machineries.

In this paper the details of rock bursts faced in two mines namely Blyvooruitzicht Gold Mine, South Africa and Kolar Gold Fields one of the deepest rock burst prone gold mines of India and Parbati Hydroelectric project, Himachal Pradesh, India are discussed in order to understand the dynamics of rock bursts and measures adopted to combat rock burst.

1.2 Definition of rock burst:

A rock burst is defined as the sudden and sometimes violent release of accumulated energy when a volume of rock is strained beyond its elastic limit. Rock bursts can be classified as strain, crush or slip. Strain bursts are small and localised, while crush and slip bursts can cause extensive damage to drifts and stopes. Scott (1997), Bennet et.al. (1977) define a rock burst more broadly as any type of stress-release phenomenon which has been induced by mining activity and which results in emission of seismic signals. Gibowicz simply referred to rock bursts as violent failure of rock, those results in damage to excavations. Knoll and Khunt (1990) have reported two types of rock burst. Type 1 refers to rock burst taking place close proximity to mine workings and another type of phenomenon called tectonic or dynamic rock burst and has termed it as Type 2 rock burst which can only indirectly be connected to the mining activities. The stimulating factor for this type of rock burst is stated to be the presence of high tectonic stresses in the virgin rockmass and the presence of geological fracture planes approximately oriented to the tectonic stress field.

A seismic event is considered to be the transient energy released by a sudden fracture or failure in the rock mass which results in the emission of a seismic vibration transmitted through the rock. A rock burst is the significant damage caused to underground excavations by a seismic event.

1.3 Classifications of rock bursts:

There is a very wide range of rock failure phenomena that is embraced by the umbrella term 'rock burst'. The range of magnitude, in energy terms, involved in the spectrum of events form superficial strain-bursting to the collapse of an extensive shallow tabular mine, can extend across 9 orders of magnitude as shown in Table 1.

Table1
Indicators of size and range of seismic events

Richter Magnitude M_L	Kinetic Energy MJ	Explosive Equivalent Kg	Radius of Source Rupture m
-1	0.002	0.04	0.8
0	0.06	1.2	2.6
1	2.0	40	8.5
2	60	1200	26
3	2000	40 000	84
4	60 000	1,200 000	270

Source: W.D. Ortlepp (2005) RaSiM6, Australia.

Rock bursts occurring in two mines namely Kolar Gold Field mines in India, Blyvooruitzicht Gold Mine, and South Africa and Parbati Hydroelectric project, Himachal Pradesh are described.

2. Kolar Gold Fields:

Kolar Gold Field is situated at 12^0 $57'$ north and 78^0 16' east in the south east corner of Karnataka in India and lies at an altitude of 900m above the sea level.

2.1 Geology:

Geologically the gold bearing hornblende schist of Kolar Gold Fields belongs to the lower Dharawar age. The gold bearing lodes dip towards west at an angle of $40\text{-}45^0$ near the surface and gradually become nearly vertical at great depth. Of the many quartz lodes explored on the fields, only two lodes –the champion and the oriental lode are of economic importance. While the champion lode has been mined extensively in all the three mining districts of Kolar Gold Fields, the oriental lode is mined on a large scale in the Nundydroog mines only due to economic reasons –Krishanmurthy and Shringarputale (1990).

2.2 Mining:

The extraction of lode is done mainly by the following methods.

i. Bottom stoping with granite support
ii. Stope driving with concrete with sand fill
iii. Flat back stoping.

The rill systems of stoping which was practised at depth in champion reef mine earlier have been replaced by stope driving.

2.3 Rock burst problems:

The problems of rock bursts associated with hard rock have been present in the Kolar Gold Fields since the beginning of the last century. They have occurred at all depths under different mining conditions. However, the problems became serious as mining reached greater depths. The deepest point reached in one of the mines is 3200 m. Rock burst have caused large scale fatalities, costly surface damages, loss of shafts. Valuable proved reserves have been lost forever. However, the problems of rock bursts have been considerably reduced due to the introduction of better mining methods, based on rock mechanics studies - Krishnamurthy, R. and Gupta, P.D.(1983). Frequency and severity of rock bursts are not directly related to depth. A large number of rock bursts of medium and major intensity have also occurred at shallow depths. The important factors for the causes of rock bursts are physical and elastic properties of rock, in-situ stress, size and shape of excavation, and the in homogeneities of the rock such as existence of faults, pegmatites, dykes and calcite stringers, all involving plane of weakness either in themselves or at contact.

2.4 Area rock burst:

Area rock burst is unique to the gold mines of Kolar Gold Fields mines. Area rock burst implies a sequence of rock bursts which follow in quick succession with their hypocentres concentrating in a smaller area of 100 -200 m radius. It so happened that the occurrence of a major rock burst triggers a series of rock bursts numbering 20 – 200 of equivalent or smaller sizes in the same area over a period of few hours to few days. Besides causing wide scale devastation to ore shoots, working shafts, drivages, steel sets etc., in the underground, area rock bursts have their damaging effects on the surface buildings also lying within 2-3 km radius of the epi-central region.

Till date more than 20 area rock bursts have been reported from the mines of Kolar Gold Fields, out of which more than 15 area rock bursts have taken place in the Champion Reef mine itself. However, full details of only 10 area rock bursts that have taken place after the commencement of round the clock seismic monitoring, are available. Some of the area rock bursts have been described by Miller (1967), Krishnamurthy and Nagarajan K.S.(1981) and Krishnamurthy and Gupta (1983).

Mining has a vital role in the genesis of the area rock burst particularly when the mining is being practiced close to the plane of weaknesses like folds, faults, dykes etc. The role of mining in inducing area rock bursts is extensively discussed by Miller (1967) and Krishnamurthy and Gupta (1983). It is stated that for whatever course of mining be adopted, there is a critical area of extraction at which major collapse will occur. However, mining being the remote region (long term effect), the role of geological features needs to be read simultaneously while assigning attributes for area rock bursts.
Mining in the area where folds formations exist, severe rock bursts were encountered in the past leading to frequent damages to shafts. The productive working in the folds formations, where the quartz attains a width exceeding 6m, it occurs in large zig-zag pattern. These lodes have been interrupted by a series of faults, dykes and pegmatite veins, all involving plane of weaknesses. Of them, two major fault planes, i.e., the Mysore North Fault lies only 8-12 m away in the hanging wall of the folded formations of the champion lode in the Northern Folds area of the Champion reef mine. The Tenants fault runs parallel to the main lode in the shallower levels and lies only 30m away in the hanging wall of the lode in the Champion Reef mine. Major rock bursts including area rock bursts were reported while mining close to these fault planes and as such their roles in inducing these rock bursts.

2.5 Seismic investigation:

A breakthrough has been made in the field of rock burst research in Kolar Gold Fields by the application of seismic techniques to study the stability of underground workings. A seismic network consisting of 14 geophones (7 on surface and 7 underground) with their electronics was established to cover an area of 8 km X 3 km on the surface. The signals picked up by the geophones were transmitted through cable driven PPM and recorded on a 24 channel magnetic tape recorder/replay system. The use of seismic technique in the mines of Kolar Gold Fields has been described by Srinivasan et.al (1997 & 1999). The block diagram of the system is shown in Figure 1.

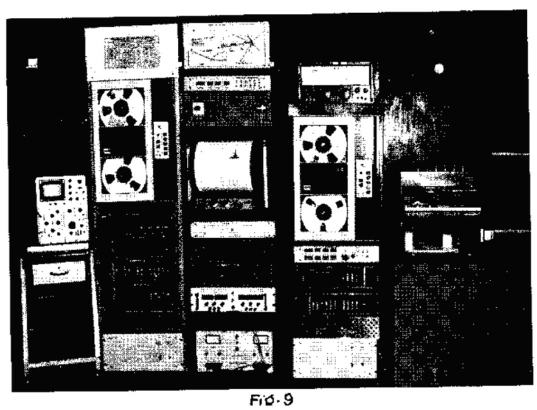

Figure 1 Block diagram of seismic monitoring station.

The rock bursts in and around the mine excavations have been continuously monitored since 1978. More than 12,000 seismic events have been recorded and hypocentres of a very large number of them determined with an accuracy of 50m. They were found to occur throughout the mining region and are distributed nearly parallel to the main longitudinal axis (North-South) of the Kolar Schist belt, Srinivasan and Sringarputale (1990). However, the seismic activity is concentrated in the vicinity of mine workings. The depth wise distribution of the rock burst events is found to be consistent with profile of the underground workings. The mining region is crossed by a major geological fault striking NE-SW (Mysore North Fault) in whose vicinity many rock bursts tend to occur. The computed foci of rock bursts recorded from the bottom section of Champion reef mine is shown in Figure2.

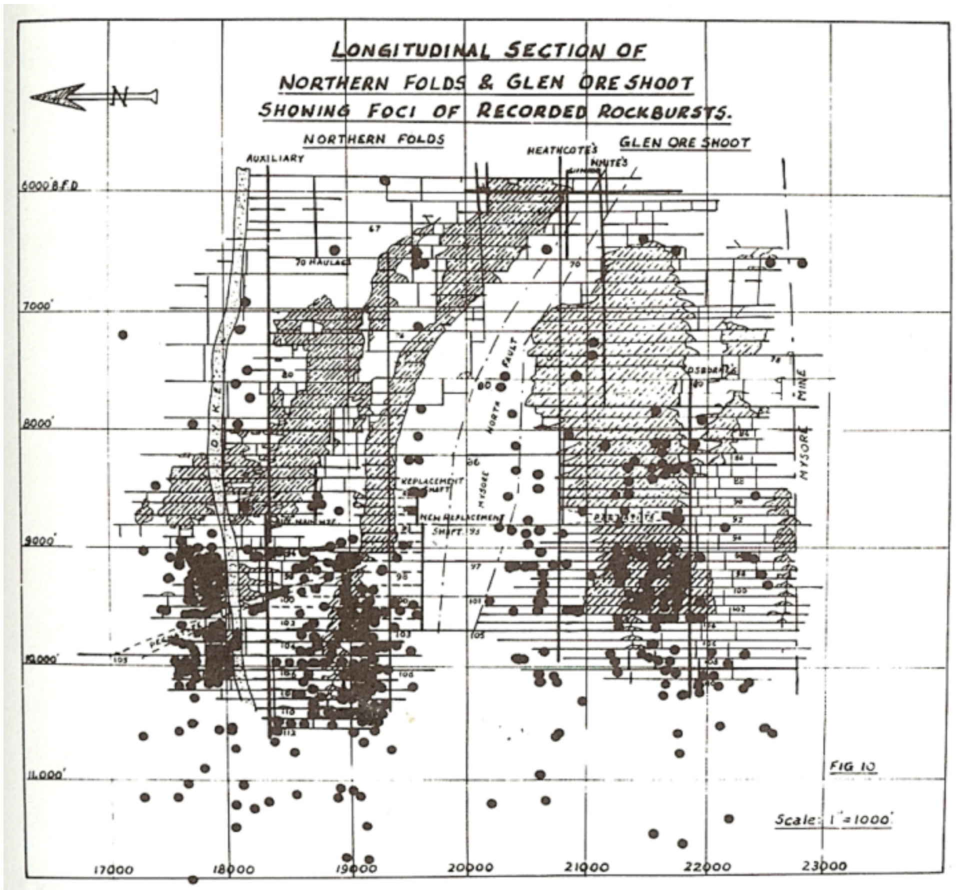

Figure 2 Computed rock burst foci from deeper levels of
Champion Reef mine in Kolar Gold Field.

A noticeable rock burst occurred on 02.11.2005 at 18:14:56 hrs with magnitude M_L 3.9 in the old and abandoned mines of Kolar Gold Fields as shown in Figure-3. The rock burst was very severe and the effect was felt by residents of adjoining areas and surrounding townships. The rock burst caused panic among the residents and it is reported that the people came out of their houses. The peak ground acceleration recorded due to the rock burst was 0.22g. Many houses/ buildings being very old are already in depilated conditions suffered damages.

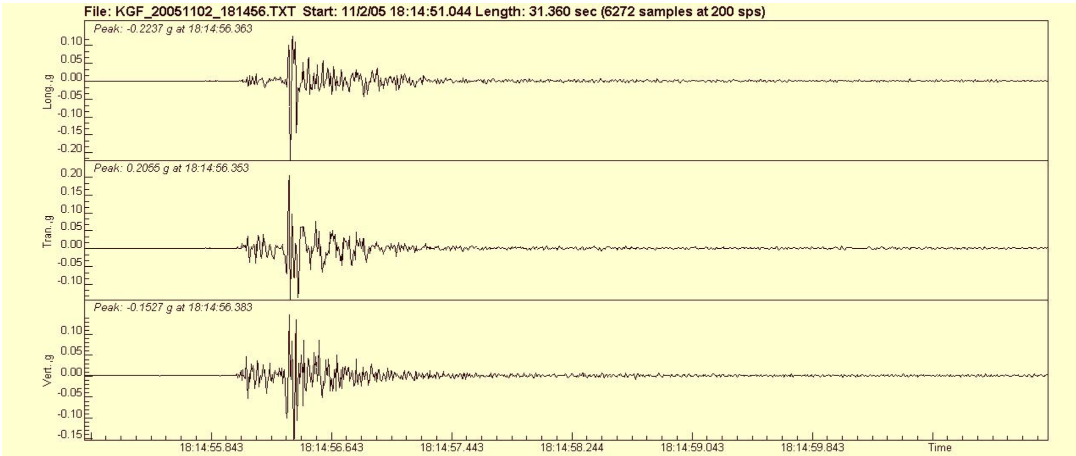

Figure 3 Major rock burst recorded by the Strong Motion Accelerograph on 02.11.2005 at 18:14:56 (UTC)

2.6 Rock mechanics investigation:

From rock mechanics investigations it has been possible to obtain useful information on the stress/strain distribution in and around underground workings and on the strata displacement characteristics of rock bursts. This has been great assistance to plan improved mining methods in areas vulnerable to rock bursts especially in the bottom section of champion reef mine and to exercise a better control over them.

The seismic monitoring of rock bursts has become a handy tool for assessment of safety of mine workings that work is either suspended or resumed on many occasions, depending on the seismicity recorded from rock burst prone areas. Analysis of seismic data collected from the seismic network helped in a better understanding of the rock burst mechanism and in choosing safer course of mining.

3. South Africa:

Rock bursts are a major risk in deep and high stress mining in South Africa, causing damage to infrastructures, loss of production, and injury and death to mine workers. Mine owners and managers are required by law to take reasonable measures to ensure that the working environment is healthy and safe when a mine is designed, constructed, equipped and operated. Seismic monitoring, analysis and interpretation are key components of the risk management system on rock burst prone mines.

Monitoring has been taking place on a routine basis in South African mines for nearly three decades, and seismic monitoring systems are now operational on virtually all rock burst prone mines in South Africa. Rock bursts are a serious hazard in the deep gold mines of South Africa. The vast majority of rock burst causalities are owing to the ejection or fall of slabs less than 1.6 metres in thickness –Roberts, (1995). As early as

1908, the rock burst problem was sufficiently serious and the Ophirton Earth tremors committee who concluded that tremors were due to the shattering of pillars.

In terms of the rock burst mechanism, Cook et.al., (1966) concluded that the "existence or otherwise of the rock burst hazard depend on whether the geometrical rate at which energy must be released, is greater or less than the rate at which energy can be dissipated non-violently as the excavation is enlarged. Salomon (1983), suggested that the hazard of rock burst could be alleviated through improvements in support systems, better layout design and the reduction of convergence through back filling or reduced stoping width.

Ortlepp (1984) out of one hundred rock bursts examined over a period of 16 years the principal findings were:

- Rock bursting is a complex phenomenon covering a wide range of magnitudes as well as modes of origin. There is no single model that can account for the diversity of the phenomenon.
- Events of intermediate magnitude, which occur within a few metres to tens of metres from the stope face, are most hazardous. Here the shape of the excavation plays a significant role in determining the magnitude and stress changes in the zone of potential instability. The instability can involve movement along an existing geological discontinuity or a fresh shear fracture through previously intact and massive rock.

Fundamental mechanisms involved in the occurrence of rockburst have been the mining hazard that is least understood and the most feared.

3.1 Blyvooruitzich Gold Mine:

A rock burst occurred at Blyvooruitzich Gold mine on 30th January 1996, causing extensive damage to the strike gully serving panels mining the 17-24 W stabilizing pillar, about 1900 m below surface as shown in Figure-4. The rock burst which fatally injured five workers, took place at 08;52 hrs while stope workers were manually transporting timber along the gully. A seismic event with a local magnitude M_L=2.2 was recorded by the mine –wide seismic network. It was followed by a M_L=2.3 within a second.

3.2 Mining environment:

The 17-24W stope was the site of a preconditioning project being conducted by the Mining technology Division of the CSIR (Mining Technology) under the auspices of SIMRAC (project GAP030 Rock burst Control). Detailed observations of seismicity, convergence and fracturing have been carried out continuously since 1990.

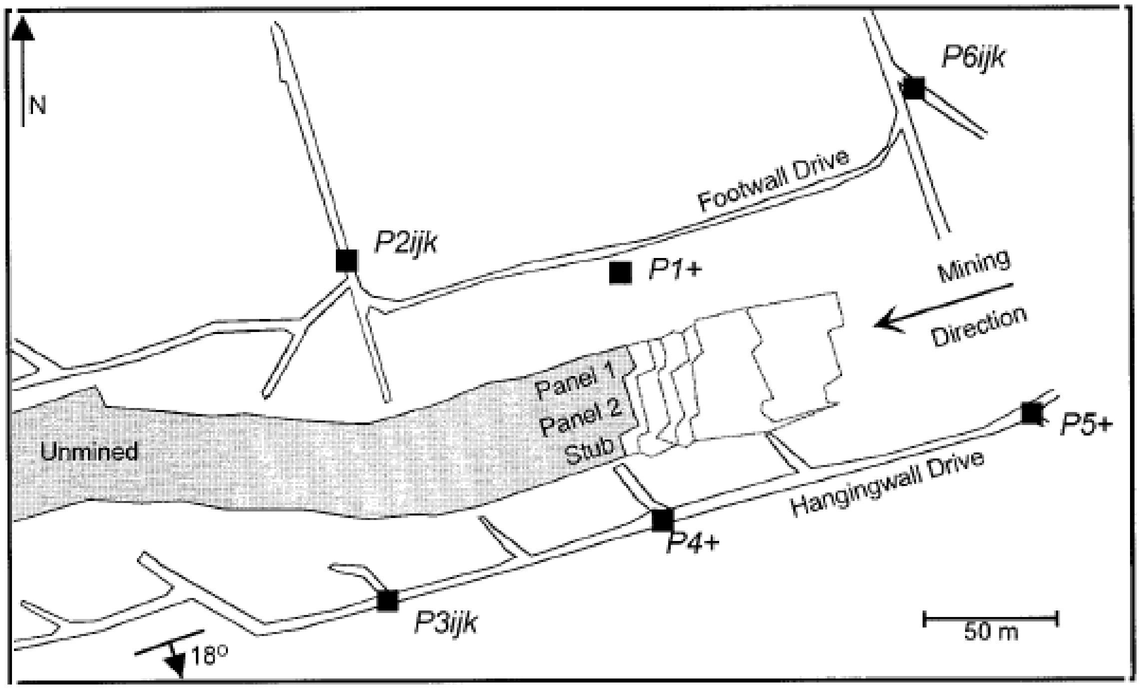

Figure 4 Plan of the 17-24W stope, Blyvooruitzicht Gold Mine, showing the layout of the panels being mined at the time of the M_L=2.2 rock burst on 30 January 1996. The position of the research seismic network, monitoring the preconditioning experiment at the site, is also shown (black squares indicate the geophone positions: triaxial geophones are labelled e.g. P2ijk; uniaxial sites are labelled e.g.P1). Face position as on at 31 December 1995.

3.3 Geology:

The ore body mined in the 17-24W stope is the Carbon leader Reef, which dips to the south at 18^0. In this area the footwall is an argillaceous quartzite, and the hanging wall is a cleaner arkosic quartzite. Approximately 2 m above the top reef contact lies a shale horizon known as Green bar. The Green Bar is several metres thick, and is comprised of dark green finely laminated metamorphosed shales. The upper and lower contacts are typical sheared and contain a variety of fault generated minerals including vein quartz, pseudotachylite and clay gouge.

There are no known major faults or dykes within the immediate vicinity of the pillar. However one of the dominant fracture sets in the pillar lies parallel to the regional trend (that is NNE to SSW) of the faults and dykes on Blyvooruitzicht Gold Mine. These prominent steeply dipping shears were initially formed by large scale tectonics and regional faulting.

3.4 Mining induced fractures:

Six major sets of fractures (group I to VI in Figure-5b) have been identified on the basis of their dip and strike orientations (Lightfoot et.al., 1996). Group III (steeply dipping shear zones) are thought to be the oldest as they are aligned with the regional strike of dykes and faults across the mine, which suggests that their initial development was owing to large-scale faulting. Associated with group III are the low-angle faults of Group VI which formed as second-order shears during the shearing of the Group III fractures. Group I and Group II fractures (pillar-parallel faults and joints with a steep to intermediate dip) are thought to have developed after Group III, as a result of mining of the surrounding ground. The shallow dipping Group II fractures later dilated as the pillar slowly failed at the edges. Group IV fractures, which lie parallel to the panel faces, formed in response to stress changes caused by the approaching mining. Group V fractures are thought to be the result of the failure in tension of the stope hanging wall in the broken rock mass immediately ahead of the stope face.

3.5 Preconditioning:

3.5.1 Mechanism:

The mechanism of preconditioning is discussed in detail by Lightfoot et.al, (1994). The rock mass ahead of a stope is subjected to extremely high abutment stresses, which result in the complex network of fractures observed underground as shown in Figure-6. Movement along the fracture planes results in the deformation of the rock mass, which is revealed by the convergence of the hanging wall and footwall in the stope. Inhibition of this movement might be induced by 'locking up' of blocks against another, resulting in the accumulation of strain energy ahead of the stope face. As the face approaches this lock up, confinement is significantly reduced, allowing movement to occur, if sufficient energy is available large quantities of rock into the working area.

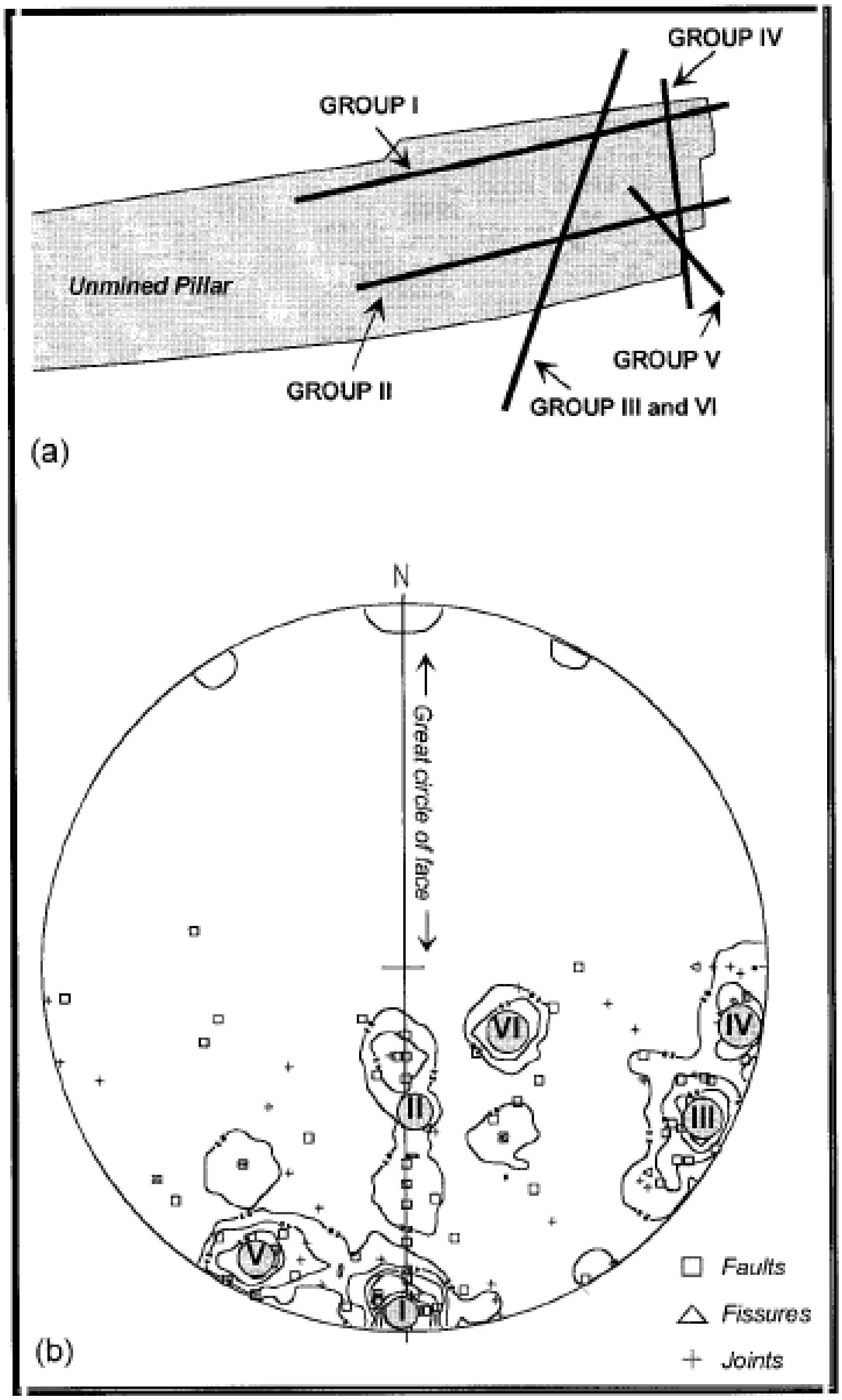

Figure 5 (a) Orientations of the six major fracture sets (groups I to VI) identified at the 17-24W site.
(b) Contoured Schmidt Net (lower hemisphere projection) of poles to all mapped fractures.

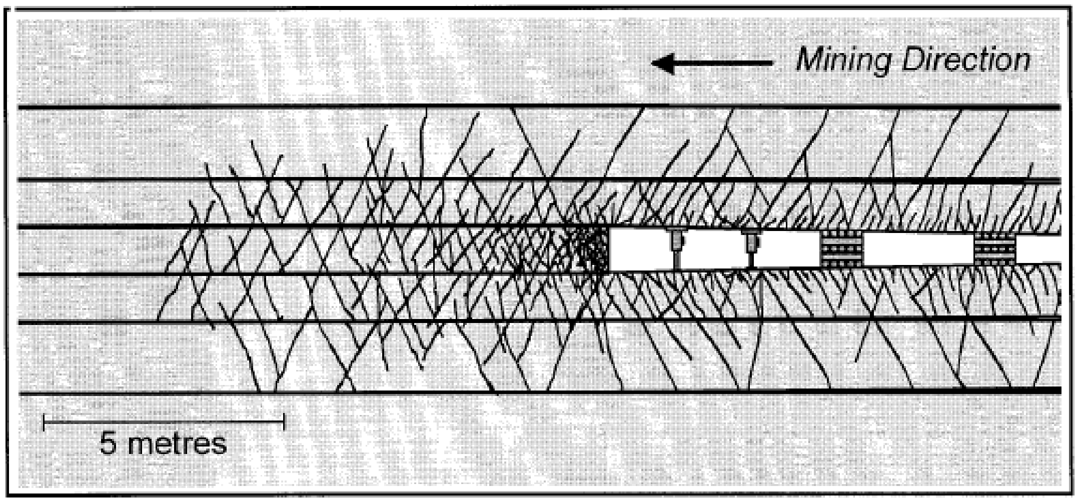

Figure 6 Schematic vertical section through a deep-level stope illustrating the fractured nature of the rock mass surrounding the opening.

Preconditioning is intended to prevent the accumulation of strain energy ahead of the working face or at least, control its release. The gas and shock generated by a blast within the rock mass mobilizes the blocks by shearing through any asperities responsible for a lock-up. Strain energy release is facilitated by the sliding of blocks past one another, thus reducing the risk of a face burst during the production shift. The stress redistribution away from the working face by a well-executed preconditioning blast provides a low stress zone ahead of the stope face which is able to absorb energy from more distant events. In this way, it is possible to minimise the extent of severity of damage that may occur from more distant events, while controlling the size and timing of seismic events near the face.

5.6.1 Seismic history:

The seismicity associated with mining the 17-24 pillar has been monitored continuously since 1990. Since the change of mining to breast mining in September 1992, 51 events with M_L>1 and 15 events with M_L> 2 have been recorded from the 17-24 pillar. Several of the larger events caused falls of ground in the strike gullies. There is no evidence to suggest that the seismicity associated with this rock burst was in any way remarkable when compared with the occurrence of the other larger seismic events at the site.

These larger events were spaced fairly evenly through the time period since September 1992. While most of the events occurred during or shortly after blasting time, three did occur at on-shift times. Of the 40 days on which large events M_L>1 took place, 11 days had pairs of such events. The events in four of these pairs were separated by more than one hour, but all of these incidents involved triggering by preconditioning or production blasting. None of the on-shift events were followed by a second large event within 24 hours.

5.6.2 Rock burst source mechanism:

The rock burst took place at 08;52 hrs on 30 January 1996. Two seismic events occurred within 1s, and were recorded by both the research (B17) seismic network surrounding the pillar and the mine-wide (BGM) seismic network. As well as by the Western deep levels South Mine (WDLS) seismic system. The seismograms recorded by the B17 network were saturated owing to the intense shaking close to the source. Consequently, the seismograms recorded by the BGM network were used in the determination of the source parameters. The local magnitude of the first event was M_L=2.2, as determined from the BGM network (the WDLS network assigned the event a local magnitude of M_L=2.3, confirmed by the National Seismic Network administered by the Geoscience). The B17 network seismograms enabled the focus of the event to be located with an error of less than 5 m. The focus was located about 20 m ahead of panel 2 and 15 m in the hanging wall of the reef (see Figure -7). The large amount of S-energy suggests that the event had a slip mechanism. The stress drop was moderate (static stress drop of about 5 Mpa). The Brune source radius was 60 m.

The M_L=2.3 event (local magnitude determined from BGM network), was located about 100 m to the north of the stabilizing pillar and in the footwall of the reef (see Figure -7). The waveforms recorded from this second event were superimposed on the tail of the first event, so the location was not determined with the same degree of confidence as that for the first event. It is thought likely that the observed damage resulted from the combined effects of both of these large seismic events.

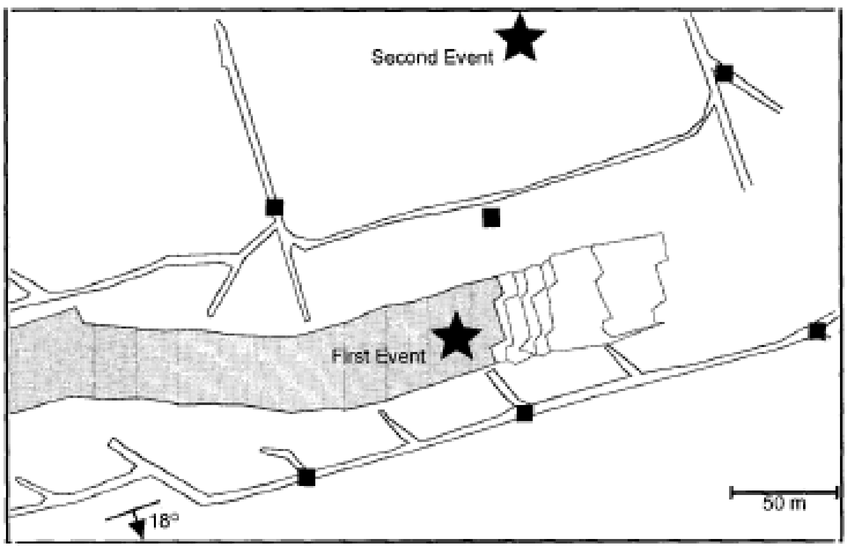

Figure 7 Plan showing the locations as determined from the research seismic network records of the Ml=2.2 and Ml=2.3 seismic events which occurred on 30th January 1996 damaging the 17-24W stope, Blyvooruitzich Gold mine.

5.6.2 Damage mechanism:

It is believed that the rock burst damage was owing to the disintegration of the highly fractured and inadequately supported hanging wall when subjected to seismic shaking. Damage is directly related to the duration of shaking. Thus the effect of the shaking was exacerbated by the second M_L=2.3 event occurring immediately after the M_L=2.2 event.

5.6.3 Strong ground motion:

The sensors of one Ground Motion Monitor were attached to the face, hanging and footwall about 5 m above the toe of panel 1. This was about 40 m from the focus of the M_L=2.2 event. This event produced shaking with a duration of about 80 ms with peak acceleration a_{max}=420 m/s^2 and peak velocity V_{max}=470 mm/s. A further four aftershocks were recorded in the 10 minutes after the main event. The two larger events (M_L=0.1 and M_L=0.5) were also recorded by the micro seismic network. Both these events produced a_{max}= 110 m/s^2. The sensors then became detached from the skin of the excavation. The monitor also recorded a M_L=1.0 event on the evening prior to the rock burst (19:33 hrs on 29 January 1996), with V_{max}= 32 m/s^2.

The enormous advance made in computer hardware and software during the past two decades has resulted in substantial progress in numerical modelling used as an analytical tool to help determine the rock mass response to mining-induced stress changes.

6. Parbati hydroelectric project, stage-II:

This study focuses on the Kullu district in the Upper Beas River Watershed, Pir Panjal Range of the Western Himalayas, Himachal Pradesh, India. The Parbati Hydroelectric Project (Stage-II) is a run-of-the-river scheme proposed to harness hydro potential of the lower reaches of the river Parbati.

6.1 Rock burst problem:

During excavation of head race Tunnel of Parbati Hydroelectric project, rock burst problems were faced frequently. Three accidents took place due to rock bursts . During the first accident on 19th November, 2004 12 workers were injured. Rock burst occurred not on the face but about 20m behind face. The second accident took place on 7th January, 2005 when completion of mucking operation, huge rock mass from crown detached and fell over the excavator and the operator died on the spot. Huge rock mass failure accompanied with cracking sound from right crown occurred. During the third accident on 20th January, 2005 sudden and violent breaking of rock mass from the drilled face, three persons died on the spot. NIRM was asked to visit the rock bursts sites and suggest suitable instrumentation for addressing the rock burst problem.

6.2 Geology of the accident area:

The rock type is Manikaran Quartzite and the rock mass at the accident area is intersected by three sets of predominant joints which was responsible for the present failure. A cavity of more than 3m is formed at the right crown as shown in Figure-8. The foliation joint S1 is very close spaced, smooth, planar, and slightly weathered to fresh in failure zone. S2 is wide spaced, smooth, planar, slicken sided, strained, dipping oblique to the drive direction at an angle of approximately 40^0. This joint was mainly responsible for this failure along with other two sets of joints. Separation of the rock mass along this joint is also observed in the cavity portion. S3 is moderately spaced, fresh and slightly rough.

6.3 Causes of rock burst:

In all the three cases of accidents rock burst was the main reason for damages observed. The incidence of rock burst occurred when excavation encountered rock Manikaran Quartzite, which was thinly foliated, fine to very fine grained, milky white colour having two prominent sets of joints. The strength of the rock is strong to very strong (R4-R5)

The rock has closely spaced foliation joints. The incidence of rock burst occurred due to stress release phenomena because of super incumbent rock cover (around 900m). Failure started from the left side of the face, which is the intersection of the two major joints. This failure occurred with strong noises from the rock, releasing heavy stresses that spread rapidly throughout the heading zone and resulted in the collapse of the heading zone.

Steel Ribs were erected upto the face with complete backfill concrete. Face drilling was almost complete except 5 to 6 holes at the bottom of the face when sudden failure of huge rock mass occurred from the heading zone accompanied with loud cracking sound (rock burst) which was similar to the face burst. This rock burst occurred from the heading zone at downstream face of Adit I as shown in figure-8. This rock burst resulted in the generation of huge force, which in turn created a dead load on the installed steel ribs along with complete backfill concrete. The entire mass of rock, steel ribs and backfill concrete buried three persons working on the Boomer killing them instantly and severely damaging the Boomer. Besides the presence of adverse joints, presence of high stress due to high rock cover was resulting in popping and rock bursting. Rock mass rating was done at the accident site and found to be class IV. The support measure as per design rock support for class rock was suggested before further excavation.

i) Shotcrete at the cavity portion and excavated face.
ii) Pattern rock bolting as per class IV
iii) Steel ribs of 0.8 m c/c with complete backfill.

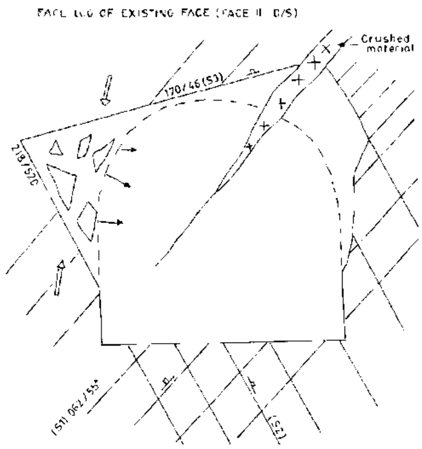

Figure 8 Face log of Existing face (Face III, D/S) – Huge Rock mass failure.
------- : Profile of the face before Rock burst
_____ : Profile of the face after Rock burst

7. Discussions:

Rock bursts are common phenomenon observed during excavation of underground mines and tunnels. Excavations cause a large stress gradient and the potential for release of the rock's stored strain energy. A gradual release of strain energy may be perfectly safe, whereas the sudden and violent releases of energy results as rockburst. Rock burst is a kind of dynamic instability caused by the sudden release of strain energy during the brittle fracturing of the surrounding rock mass around underground openings, in which the fragments of fractured rock are projected out.

In the case of Kolar Gold Fields, the rock burst problems were not commonly faced except while mining shaft pillars and in exceptional cases, ore shoots which were highly stressed due to juxtaposition of faults. However, these problems became serious as mining reached greater depths, particularly when the ore body to be mined was associated with faults, pegmatites and dyke all involving planes of weakness. Many major area rock bursts occurred subsequently with mining undertaken at greater depths, causing extensive damages to the underground workings and surface buildings. Rock mechanics investigations into the problem of ground control were carried out by many in early days and after the formation of rock burst research unit, systematic investigations of ground control was carried out.

The application of instrumentation mainly consisted of borehole extensometer, lateral extensometer and stress meters to study the stress build up in abutments both in the wall rocks as well as on reef with strata movement characteristics. Continuous recording of stress/strain measurements were introduced. The important findings were the Kolar rocks are very strong with high modulus of elasticity. The violence of rupture of KGF rocks was found to be 2 to 3 times higher than those of South African quartzite. High lateral stresses that can be super incumbent weight alone exist in the virgin rock. In some cases, it is found to be higher than the vertical stress field. High abutment stresses exist very close to the face indicating that the fractured zone embracing the excavation is very limited.

Based on the findings, the following recommendations were made for stoping at deeper levels.

a) Adopt a technique of geometrically designed sequence which permits considerably increased rate of advanced to be achieved and maintained, limit the area to be exposed in each machining cycle to the minimum and adopt quick support systems.
b) Adopt a support system which yields and provides relief to the rock mass but is sufficiently strong to support the immediate walls thus deliberately assisting the main body of the rock mass to attain static and dynamic equilibrium quickly.

As per the above new recommendations, mining systems were evolved both for Champion reef mine at depth and Nundydroog mine. By adopting these practices, frequency in the incidence of rock burst considerably reduced.

A real break- through in the field of rock mechanics investigation of the Kolar Gold Field was the setting up of seismic and micro seismic monitoring system to study the seismic activity during mining operation and assess the stability of mine workings including fore warning of the occurrence of rock burst. The seismic monitoring has helped to precisely locate the foci of rock burst with an accuracy of 50m and delineate areas of high stress in the mining area which ultimately resulted in rock burst. The latest art of the technology in mining seismology has been used in the mines of Kolar Gold Fields which enabled to understand the dynamics of rock burst.

The seismic monitoring of rock bursts was proved to be a "handy tool" for assessment of safety of mine workings that the mine work is either suspended or resumed on many occasions, depending on the seismicity recorded from rock burst prone areas. The important factors for the causes of rock bursts are strength and elastic properties of rocks, in-situ stresses, size and shape of excavation, supports and the in homogeneity of the rocks such as the existence of faults, dykes etc.

Rock bursts are a major hazard in South African deep-level gold mines. The severity of damage due to a seismic event often varies greatly over small distances as discussed above in the Blyvooruitzich Gold Mine. It is believed that a detailed understanding of the damage mechanisms, and the application of this knowledge to the design and support of excavations, will lead to reduction in the hazard posed by rock burst.

Detailed investigations of rock burst were carried out by inspecting the damage to the excavation after rock burst, mapped mining induced fractures and other geological features.

The enormous advance made in computer hardware and software during the past two decades has resulted in substantial progress in numerical modelling used as an analytical tool to help determine the rock mass response to mining-induced stress changes.

In the Parbati hydroelectric project, besides the presence of adverse joints, presence of high stress due to high rock cover was resulting in popping and rockburst in the excavation of head race Tunnel. Rock mass rating was done at the accident site and found to be class IV. The support measure as per design rock support for class rock was suggested before further excavation

8. Conclusions:

At Kolar Gold Field Mines, mining was carried out at considerable depths and very high vertical gravitational stresses exist at these depths. Most of the rock bursts in Kolar Gold Fields mines have occurred at depths were due to vertical gravitational stresses and stress concentration around openings which led to sudden ruptures. The important factors for the causes of rock bursts are strength, elastic properties of rocks, in-situ stresses, size and shape of excavation, supports and the in homogeneity of the rocks such as the existence of faults, dykes etc.

For prevention and control of rock bursts in Kolar Gold Fields it is essential that all workings and their supports should be planned around them which do not exceed rock strength. The Kolar rocks are very strong with a high modulus of elasticity. The violence of rupture of KGF rocks was found to be 2 to 3 times higher than those of South African quartzite.

The maximum principle stress in South African mines, for instance are predominantly compressive and sub-vertical that leads to Moment tensor solutions with deviatory components dominated by normal faulting and volume closure.
In the Parbati hydroelectric project, besides the presence of adverse joints, presence of high stress due to high rock cover was resulting in popping and rockburst in the excavation of head race Tunnel.

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