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Rockburst and Fall of Ground Investigations in Deep Level Gold Mines: South African Example

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ABSTRACT: South Africa's mineral industry is supported by an extensive and diversified resource base. It has a third or more of the world's reserves of alumino-silicates, chromium, gold, manganese, platinum-group metals vanadium and vermiculate etc. This large reserve base allows it plays an important role in the world in respect of the production and exports of many minerals and also some processed mineral products. Rock related accidents have been the major problem in the South African mining industry for many years. According to the latest South African statistics, 50 % of the accidents are rockfall and rockburst related (rock-related). Although three has been a steady a decline in accidents in the industry, the rock-related accident rates are still far from being satisfactory. The author conducted considerable number of rock-related accident investigations and inquires in various deep level gold mines, and the conclusions of the accident investigations and inquiries revealed that most of the accidents occurred as a result of lack of support units in the working face area, poor mining practice, lack of hazard identification, poorly designed mining and support layouts and lack of strata control training for workers. The main objectives of this study are firstly to describe the structure and importance of the mining industry for the South African economy and secondly to introduce and determine the causes of the rock-related fatalities in the South African gold mines.

I INTRODUCTION

South Africa's mineral industry is an important contributor to the country's economy. South Africa's total primary mineral sales revenue in 2001 was $13 billion, and the major foreign earnings in 2001, remained the platinum group metals (32,70 %) overtaking gold for the first time, followed closely by gold (31.90 %) and coal (18,90 %•)• Mining contributes around 7,5% directly to GDP and an estimated 15% through associated multiple effects.

2 STRUCTURE OF THE SOUTH AFRICAN MINING INDUSTRY

For more than a century. South Africa's mineral industry, largely supported by gold, diamond, coal and platinum production, has made an important contribution to the national economy. Furthermore, it has provided the impetus for the development of an extensive and efficient physical infrastructure and has also contributed greatly to the establishment of the country's secondary industry.

The mineral industry is a well-establishment and resourceful sector of the economy, and has a high degree of technical expertise and the ability to mobilize capital for new development. Table 1 and table 2 indicate that the mining sector is recognized worldwide as a leading and reliable supplier of a large variety of minerals and mineral products of a consistently high quality. In 2001, some 55 different minerals were produced from 775 mines and quarries, of which 69 produced gold, 83 coal, platinum 18 and 58 diamonds. Mineral commodities were exported to 92 countries. According to the 2001 statistics, 407,000 people arc employed in the mining industry.

The government's economic policies arc based on principles of private enterprise and free-market mechanism. The system has enabled the mineral induslry lo develop without undue state influence, thereby allowing market forces to dictate the pattern of its development. The Department of Minerals and Energy Affairs (DMEA) is responsible for the administration of the Minerals Act, 1991 and Mine Health and Safety Act, 1996, which regulate the prospecting for, and optimal exploration, processing and utilization of minerals, safety and health in the mining industry etc. respectively.

The DMEA's mission is to provide for effectual governance of the minerals and energy industries for economic growth and development thereby improving the quality of life of the propel of South Africa.

The Chamber of Mines of South Africa is voluntary membership, private sector employers' organization founded in 1889, three years after gold was discovered on the Witwatersrand. The chamber is an association of mining finance companies and mines operating in the gold, coal, diamond, platinum, asbestos, lead, iron ore, antimony and copper mining sector.

The National Union of Mine Workers (NUM) is the biggest union in South Africa, which was formed in December 1982. The NUM is the largest recognized collective bargaining agent representing workers in the mining and electrical energy sectors.

Table I: South Africa's mineral industry s ıcserves. 2(XX)

Commodity	World reserve °/t	**World ranking**
Alummo-silicate	37.4	1
Chrome ore	68,3	1
Gold	35.0	1
Manganese	80.0	1
Coal	10.6	5
Phosphate	7.2	3
Platinum	55.7	1

Table V South Africa's role m world mineral exports, 2000

Commodity	World production %	**World ranking**
Alumino-sihcate	49.8	1
Chrome ore	28,9	1
Coal	11.9	3
Manganese	28.5	1
Vanadium	69.0	1
Zirconium	32.3	2

3 MINE HEALTH AND SAFETY ACT, 1996 (Act No 29 of 1996)

The Act is dedicated solely to health and safety within the mining industry, which was not the case with the amended Minerals Act. The main objectives of the Act are;

- to provide for employee participation in the matters of health and safety;
- to protect health and safety of persons at mines;
- to provide effective monitoring of health and safety conditions at mines;
- to provide for investigations and inquiries to improve health and safety at mines; and
- to require employers and employees to identify hazards and eliminate, control and minimize the risks relating to health and safety at mines.

4 ACCIDENTS IN SOUTH AFRICAN MINES

The South African mining industry has for the past years been trying to reduce the expenditure on all major and minor cost in an attempt to either keep profits up to acceptable levels, or in many cases, to prevent the mine from making a loss. A big pressure in the filed of heath and safety has also been experienced for unions, employers and state to see a significant reduction in the fatality and injury frequency rates. The type of accidents in the South African mining industry both fatality and injury are indicated in the table 3. The safety situation is still far from being satisfactory as per Table 4.

Table 3: Type of accidents in South African mines, 2000

Type of accident	**Fatality**	**Injury**	Total accidents
Rock related	142	1265	1296
Machinery	12	229	239
Transport	45	920	960
Electricity	6	46	48
Fires	0	4	4
Explosives	3	47	48
Heat sickness	2	16	18
Gas/fumes	18	31	38
Conveyance	4	32	34
General	53	2138	2166
Rate	0.72	11.92	
Total	285	4728	4851

General: miscellaneous, occupational diseases, diving sickness, inundation, struck by objects, slipping, falling etc.

Table 4: Total accidents in South African mines. 2001

	1997	1998	1999	2000	2001
FATAL	424	366	315	285	301
INJURY	7100	6056	5488	4728	4722

Table 5- Total injuries & fatalities in specific mines. 2001

Year	1999	1999	2000	2000	2001	2001
	I	F	1	F	1	F
Gold	4202	21.3	3549	173	3372	192
Coal	207	28	213	31	171	17
Pt	765	39	638	46	795	50
Otheı	314	35	332	35	422	27
Total	5488	315	4728	285	4760	301

Table 6: All mines rock-ielated accidents. 2000

	1996	1997	1998	1999	2000
Fatal	247	192	181	137	142
Injury	2184	2012	1819	1517	1265

Table 5 also indicates the fact that most of the accidents occur in the gold mines. As it can be seen in the table 6 most important issue in the mining industry is the *rock-related* accidents such as roekburst and falls of ground.

In this research, most attention will be focused on the South African gold mines, which not only has higher total casualties than other hard rock mines, but also experiences more severe hazards, notably a high incidence of roekburst in the deep level gold mines.

4.1 South African Gold Mining Industry

Gold is synonymous with South Africa. Approximately 31% of the world's gold has been mined in the country over the past decade. Today, the Goldfields from a discontinues arc, 430 km long, stretching the Gauleng, the North-West, the Mpumalanga and the Free State provinces. In 2001, 395 t of gold (at 5-6 g/t average grade) was produced by primary gold mines, tailings re-treatment operations and as a by-product of the production of the other metals.

Gold mining in South Africa, from its humble beginnings in the first recorded mine in Eesterling in the Northern Province in 1871 to its pre-eminence as the largest gold mining industry in the world, has played a significant role in the economic development of the country over the past 120 years. Through gold mining, many towns and cities have come into being. Notable example is Johannesburg. Much of the infraslruclural development of roads, electricity generation, water reticulation, telecommunications, housing and the development of industry to provide the inputs to the gold mining industry have resulted directly from gold mining.

Most gold mining companies exploit more than one reef-vein in the Witwatersrand Supergroup. Further exploration, although at a reduced level, is expected to ensure that recent production levels are maintained for at least the near future. Precise age estimation in the Witwatersrand Basm is difficult since the rocks were deposited by sedimentation approximately 2700 million years ago. before the age of fossils. Experts believe that a great inland sea existed in what is now the Highveld and the Free State plains. Successive layers of conglomerate containing pebbles and gold were washed down into the sea and spread over the bottom by wave action. The gold particulars subsequently settled in successive layers of pebbles along the shoreline of this sea which layer sitted up.

4.2 Mining gold in South Africa

South Africa's thin but extensive gold reefs often lie several kilometers beneath the earth's surface and usually slope through the ground at up to 25°. The country's gold mining industry has to sink the deepest mine shafts in the world sometimes close to 4 km in-depth in order to that miners can reach and extract these reefs. The mining method in the deep gold mines is the 'longwall' mining method and the mining operation is carried out in hard brittle quartzitic rock, often at extreme depth. The great bulk of this rock mass behaves clastically, but stress concentrations around the excavations cause stable, as well as sometimes unstable, fracturing to take place. The vertical component of the virgin stress m South African mines tends to increase with depth approximately 0,027h(MPa)-rock density 2,75 t/m^3 in each meter. The rock temperature can reach up to 50 C° and this requires use of ice and refrigeration facilities.

Today, with the tremendous pressure on profit margins in the gold mining industry, which is mining steadily declining grades at ever-greater depths, there is more, emphasis on mechanization then ever before. Among the many aspects of mechanization, which are the focus of on-going research, are technologies like trackless mining, backfill, non-explosive breaking and hydropower.

On average, only 5 ppm of every ton of ore mined are actually gold. It is therefore necessary to separate the precious metal from the more than 100 million tons ore milled each year in South Africa. The Carbon-in pulp (CIP) method, which is increasingly widely used, makes use of the tremendous physical affinity "activated" carbon has for gold, which it readily attracts to its surface in cyanide solution. After smelting which takes place on individual mines, bullion bars containing about 85% gold are then taken to the Rand Refinery near Johannesburg and processed to either 99,5% purity or 99,9% purity to meet specialized demands from certain industries.

Despite the fact that the gold industry's contribution to mining and the economy has declined, it remains a vital sector in the South African economy as it can bee seen in the table 7. Gold mines provided 185,000 direct job opportunities in 2001. Moreover, through its linkages in the domestic economy, about 220,000 additional jobs are also maintained in the rest of the economy. The direct contribution in terms of salaries and wages amounted to $1,7 billion during 2000. South African gold production is pioneer in the world and will still remain as world-class gold producer in 2T[l] century.

Table 7- South African gold output. 2002

Year	**Fine Gold- ton**
1998	464
1999	449
2000	427
2001	393
2002	395

4.3 Accidents in South African Gold Mines

In 2001, 192 fatalities occurred in gold mines in which 50 % of these fatalities were rock related as per table 8. Accident statistics in South African gold mines cannot be compared with other countries' due to the following reasons:

1 - Most of the gold mines are currently working in 2500 km below surface.

2- Deep mines subjected to very high states of rock stress and cause seismicity and rockbursting.

3- In all deep mines, the exposed rockwall s are highly fractured.

4- The heavy faulting encountered in many deep gold mines and generates strata control problems and seismicity.

5- Gold mines in South Africa are the largest employees in the industry and employ more than 185,000 workers.

Table X. Rock lelated fatalities in the South African gold mines. 2000

FATALITIES	YEAR			
	97	98	99	00
GRAVITY	73	81	68	57
ROCKBURST	SO	62	41	48
TOTAL	153	143	109	105

In South Africa rock-related accidents are classified in two groups. Firstly *gravity accidents,* which accidents occur as a result of mainly unsupported of a rock or portion of fractured rock fall in the working environment. Secondly, *rockburst* accidents, which occur, as a result of stress-strain build up in the rock face or geological discontinuities such as fault or dyke and sometimes cause fatality and/or damage to underground workings.

In gold mines rockfall and rockburst accidents represent the most important cause of all fatal accidents. The important finding of the investigations revealed that 72% of all rock related accidents were seismic, and 28% of them were gravity related accidents. In 25 accidents, total death toll was 38. All gravity related accidents could have been prevented if the support had been installed prior to the accidents. Accident investigations and inquiries also revealed that most of the damage mechanism of the seismic related accidents could alsobeen minimized if the designed of the mining layout and support had been adhered by the production staff. Other important finding of these investigations was that most of the seismic related fatalities occurred between the support units due to seismic shake down.

5 ACCIDENT INVESTIGATIONS IN MINES

J. / *Accidents to be reported & investigated*

When an accident causes the immediate death of any person(s) as a result of rockfall or rockburst, the place where the accident occurred cannot, without the consent of the inspector of the DMEA, be disturbed or altered before such place has been inspected by an inspector, unless such disturbances or alteration is unavoidable to prevent further accidents, to remove corpses and injured persons or to rescue persons from danger, or unless the discontinuance of work at such place would seriously impede the working of the mine or works: provided that should an inspector assigned by the Chief Inspector fail to attend within three days after

N»,

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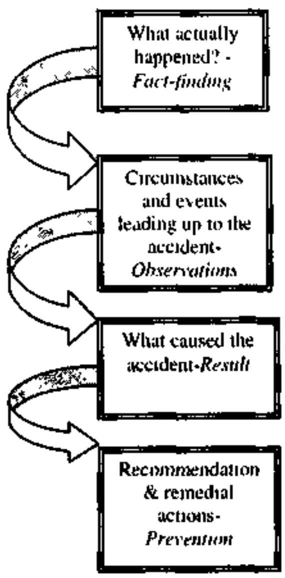
notice of the accident has been given, work may be resumed at the working place concerned.

In terms of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996) the Chief Inspector of Mines of the DMEA instructs an inspector to investigate any accident or occurrence at a mine that results in any death, serious injury, any occurrence, practice or condition concerning safety of person(s) or any actual or suspected contravention of, or fail to comply with, any provision of the Act.

Method of Accident Investigation



6 SEISMICITY AND ROCKBURST IN SOUTH AFRICAN MINES

The term "rockburst" first received official recognition in 1924, with appointment by Government of the terms of reference were "to investigate and report upon the occurrence and control of rockburst in mines and the safety measures to be adopted to prevent accidents and loss of life resulting therefore".

Rockburst can be defined as "seismic event which involves brief, violent movements of the rock mass and which causes fatality and noticeable damage to an excavation."

Mining excavations induce elastic and then inelastic deformation within the surrounding rock mass. The elastic strain energy accumulated in a portion of the rock mass may be gradually unloaded due to the passage of mining, or it may be released gradually or suddenly during the process of inelastic deformation. Therefore, seismic event is a "sudden inelastic deformation (release of the strain energy stored in the rock mass) within given volume of rocks i.e. seismic source that radiates detectable seismic waves."

Table 9: Rock ıelated accidents, death and injuries in all mines. 2000

	Accidents	Killed	Injured
Giavity	993	94	943
Rockburst	303	43	322
TOTAL	1296	142	1265

Rockburst has been a matter of concerned on the South African Mines especially in deep level gold mines for many years. Whilst the total number of injuries and fatalities has been dropping steadily, the rates have remained essentially constant for many years. Table 9 shows that the number of fatalities resulting from rockburst is 30% of all rock-related accidents. Table 8 indicates that 105 rock-related fatalities took place in gold mines, which is almost 75% of all rock-related fatalities that took place in all South African mines. Table 8 also shows that 46% of all rock-related accidents that took place in gold mines were rockburst related. Mines is South Africa are planning to extract ore at depth of 4.5 km's and deeper in the next 10 years, it is clear that serious steps are needed to minimize the risks implicit in mining at a great depth. In essence the safety of the underground workers is paramount.

6.1 Seismic monitoring in gold mines

Most of the seismicities in the South Africa mining region is mining induced. Most of the seismic events are categorized as being face driven, geological driven (local) and regional driven. That is why most of the African deep level gold mines are equipped with seismic network system for warning, prevention and design purposes.

The recognition of the hazards posed by seismicity can be quantified through seismic observation i.e. experience over time in a particular environment. That is by having seismic information from particular environment for a period of time. The hazard of large events associated with major geological discontinuities can also be inferred by knowledge of the structure and the mine layout. It can be recognized without having had prior seismic information, which then implies that it can be estimated even before mining starts in an area i.e. 'non-monitor' recognition of hazard substantial research investment is being made in South Africa to understand the physical processes, the development and evaluation ol early warning concept

6 2 Seismic emission and rockburst control in gold mines

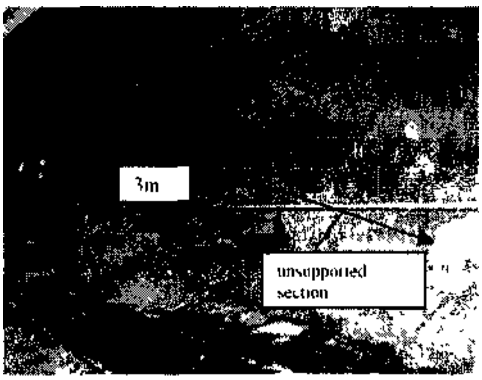
Mines must take all reasonable procedures and techniques adopted to prevent 01 reduce seismic emissions. These can be achieved by implementing stabilizing or bracket pillais, backfilling, proper mining configuration and sequencing, limitation of excess shear stress (ESS) on geological feature, mining of dykes, face shapes, limitation of energy telease rate (ERR), face advance rate, remnant iemüval, mining of dykes, mining away from structures, hydraulic props, seismic monitoring for prediction or any other preventive procedures.

7 CASE EXAMPLES

Case 1 Rockburst damage to tunnel

A seismic event with magnitude ML= 1,5 caused 2 fatalities and considerable damage to a tunnel 2,000 m below surface as per photo 1. The tunnel concerned was located some approximately 20 m beneath stabilizing pillar which was being mined out at the time of the accident. The tunnel was shotcreted and rockbolted in the some section of the tunnel, and the crew was in the process of drilling additional rockbolts prior to the accident. During inspection at the scene of the accident, approximately lm oi sidewall ejection along 15 m of the tunnel was evident 15 previously installed old rockbolts were sheaied as result dynamic loading.

A key factor controlling the distribution of the damage was the type ot support in place at the time of the accident. It was observed that some section of the tunnel had been left unsupported (mesh & lacing + lockbolts) tor a long time, and pillar extraction process in a highly stressed area above the tunnel was in progress, and this allowed further deterioration and stiess build up aiound the tunnel.

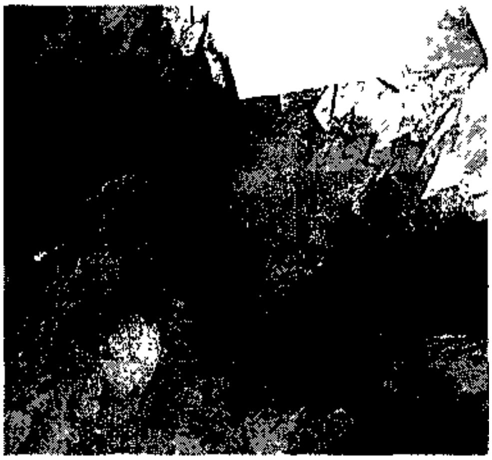


Figuie I Sidewall ejection as aiesult ot lockbuist

Case 2.Fall ofsround-support/backfill

The stope was located some 2,500 m below surface when the falls of ground accident occurred as per photo 2. 3 workers were struck by falls of ground during stope face examination prior to the accident.

It was observed that the stope panel concerned had already been backfilled in conjunction with pre-strC'Sable timber elongates approximately 6m from the face. There was no any other support unit within 6,5 m distance at the time of the accident. The fall out thickness was 1,5 m and extended along the 30m along the longwall face. Most evident issue was that the permanent support distance-backfill was far beyond the mine's standard, and the deceases accessed an unsupported stope face. It was also clearly evident that the backfill bags had not been pioperly placed, and left gaps between the roof and bag interfaces.



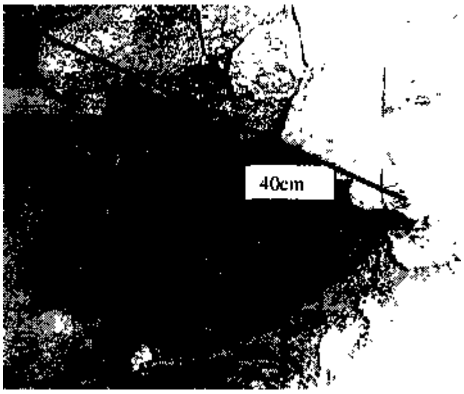
Figuie 2 Fall ot giound in a stope

Case 3. Rockburst - minute layout

3 in-slope members were fatally injured almost 3,000m below surface when the seismic event of magnitude ML=3 on the Richter scale occurred as per photo 3. The epicentre of the event was located about 20 m ahead of the panel. The stope panel was part of a longwall being mined on breast, and approaching a scismically active fault at the time of the accident. The original sloping width of the panel was 1,5 m prior to the accident, and approximately 1 m of dynamic closure approximately 4,5 m from the face was measured after the accident. The critical question to be answered in this case: what wast the cause ol the intense damage mechanism?

After having many inspections and studies, a slip type of event was determined, most probably high stress-strain build up on the major fault concerned.

In this case there was no in-situ bracket pillar had been left along the active dyke. The mining of the panel was not being mined and supported (no consideration for backfill & hydraulic props) as per rock mechanics engineer's recommendations.



Figuie 3. Complète closure in the slope

Case 4. Shaft pillar extraction

The extraction of a shaft pillar late in the life of a shaft demands the most stringent planning, since stress and safety conditions in the pilar are now at their worst. The exercise in fact be thought of as the removal of a large and probably seismically hazardous remnant, containing, important installations whose well being usually needs to be preserved.

A seismic event with a local magnitude of ML=4,1 on the Richter scale occurred in a shaft pillar extraction area approximately 2000m below surface as per Figure 4.

The tunnel was heavily supported by means of longanchors, rockstuds and mesh and lacing system. Damage to this service excavation was associated with massive footwall heave from the north side, and bulking of approximately 1,5m of the top corner of the south sidewall, and some bulging of the mesh and lace support was also evident. The area of damage associated with small dyke, and approximately 25m below the stope panel.

In this case shaft pillar was being mined out in seismically active 2 major faults, with potential to unclamp a structure while mining close-by. At the time of the incident much mining was taking place towards shaft, which increased the risk of damage to the shaft. Mining the shaft pillar area significantly increased the size of the excess shear stress-ESS areas, with associated increase in risk of slip on these structures.

Figure 4 Rockburst damage mechanism in a deep level tunnel

The steel guides in the shaft have buckled into shaft compartment as per Figure 5. Large slabs of the concrete shaft lining had been broken off and fallen into shaft. In the hoist chamber the chassis of large electric motor pinned into the foot was broken on all four corners.

Figure 5 Veıtıcal closure of about 0.5m caused severe damage to the shaft steel work

8 CONCLUSIONS

Over the years, the South African had rock mining industry sustained, and continues to sustain, a high level of rock related accidents, and the resulting rate of human casualties (injuries and fatalities) has been, in world-wide terms, unacceptably high. Of these accidents-2000, 48% of all accidents have been rod,-related, that is, the result of rockfalls or rockbursts. In gold mines rockfall and rockburst accidents also represent the most important cause of all fatalities. In 2000. 61% of all fatalities took place in gold mines of which 82% of all accidents that occurred in gold mines were rock-related.

The author conducted and analysed many rock-related accident investigations in order to determine the actual causes. The investigations and the inquires revealed that most of the fatalities and seismic damage mechanism occurred in the deep level gold mines could have been minimized if the fallowings were in order;

1. Installation of the support as per mine's standards;
2. Lack of support installation and areal coverage (backfill etc.),
3. Non-adherence to designed mining layout & sequences-poor mining practice,
4. Lack of rock-related hazard identification & training,
5. Appreciation to seismic monitoring and prevention in mines.

The amount of seismicity and rock-related fatalities in mines can be reduced if the fallowings are taken in to account:

- By keeping or introducing *backfill support* in all deep level gold mines in terms of strata control, regional support, environmental control, ERR control etc.
- *Rock engineering* services can make great contributions to the rock-related safety of the mine. All rock mechanics personnel should be legally appointed so that they can speak and express themselves in management language in order to get their rightful recognition.
- Rock-related *risk management* should be integral management system of the mine to reduce accidents.
- Rock-related accidents can be reduced significantly by *training* the workers in strata control and support issues.
- In-stope face support system must be closed to the face as possible and the support should have a sufficient *areal coverage*.
- Adherence to *layout design* and extraction principals of the mine's rock mechanics department.
- The mining of remnants & pillars should be avoided.
- A proper methodology needs to be developed in order to mine out highly stress pillars safely.
- The concepts and tools for *seismic prediction* in South African mine has been developed, and the results are appreciated and valid in the more holistic approach towards the assessment and management of seismic risk.

The mining industry in South Africa especially deep level gold mines is still working hard to improve its safety and productivity records. The gold mines are to be in a position to enjoy continued long-term success, and therefore they will utilize the most advanced technology available to reduce rock-related fatalities and injuries.

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