Apr 13th - Apr 17th

The Law and Mechanism of Rockburst Occurring in Huize Lead—Zinc Mine

Tang Shao Hui
ChangSha Institute of Mining Research, Changsha City, China

Jin Chen
Chihong Zinc-Germanium Limited Co., Yunnan Province, China

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

THE LAW AND MECHANISM OF ROCKBURST OCCURRING IN HUIZE LEAD—ZINC MINE

Tang Shao Hui
ChangSha Institute of Mining Research
Changsha City, P.R.of China

Jin Chen
Chihong Zinc-Germanium Limited Co.
Yunnan Province, P.R.of China

ABSTRACT

Rockburst is a geological disaster of dynamic equilibrium loss. According to the rock core disking and the schistose scaling on the sidewalls of cross-cut drift found in the drilling exploration of engineering geology and the site investigation in the property of Huize lead-zinc mine,the basic law of rocktburst occurring in this mine is summed up;According to the results from the site investigation and the rock mechanics tests in the laboratory,the genesis and mechanism of rockburst are analyzed to provide the important basis for selecting a reasonable deep mining method and controlling the rockburst.

Keywords: Underground mine, Rock core disking, Schistose scaling, Rockburst

INTRODUCTION

Rockburst is a geological disaster of dynamic equilibrium loss,resulting from that hard and brittle host rock,which was in a state of high in-situ stress in the excavating of underground works,unloaded so as to make the sidewall stress differentiate and the elastic strain energy storing in rockmass abruptly and dramatically release,thus the bursting,loosning,scaling,shooting and throwing phenomena of rock were produced.This strain energy storing in rockmass accumulated and generated in the long historical epoch due to the movement of earth's crust.At present,there is a different extent of rockburst in mines in more than 20 countries and regions in the world.With an increase of mining depth in underground mines,the threat of rockburst to mining production tends to be great increasingly.At the beginning of 1980s,several new hypotheses about rockburst failure mechanism,based on the new achievements of theoretical development in the modern rock mechanics,have been presented in the academic field at home and abroad,in which include equilibrium loss theory,fracture theory,damage theory and abrupt change theory.Rockburst is a very complicated phenomenon of dynamic equilibrium loss,so the knowledge of rockburst mechanism has not been unified up to now.

Huize lead-zinc Mine is the main base of lead and zinc production in Yunna province. In recent years, several mineral deposits worthy to be mined were discovered subsequently. A different extent of rock core disking was found in the process of geological drill hole exploration of Qilinchang 8# and 10# orebodies and Kuangshanchang 1# orebody. Meanwhile, schistose scaling of sidewall, which was more typical, in the cross-cute drift was found in the process of site investigation at 1# and 10# orebodies. According to the results from the site investigation and the rock mechanics tests in the laboratory, the law and mechanism of rockburst occurrence are analyzed to provide the basis for preventing and controlling the rockburst in the process of mining in future.

ENGINEERING GEOLOGY OF MINING AREA

The mining area is located at the southwestern edge of Yangtze metaplatform,and at the northeastern end of thrust structure zone of Kuangshanchang—Jinniuchang anticline on the eastern edge of the northeastern fold beam in Yunnan.The developing eastnorthern folds, faults, along-faults and near-faults in the mine area are favourable to the spacial distribution of mineral deposit. The structure of mine area was patterned toward the eastnorth-westsouth direction, which was characterized firstly by schuppen structure, and secondly by the westnorthern-eastsouthern structure.The results, which in situ stress was tested by using AE technique, have shown that the linear regression equations for the stress varied with depth H(meter) in the strike perpendicular to strata(σ_{h1}), the strike along strata(σ_{h2}) and the plumb line direction(σ_v) of $10^{\#}$ orebody are presented respectively:

$$\begin{aligned} \sigma_{h1} &= -2.62 + 0.0219H \\ \sigma_{h2} &= 1.01 + 0.0288H \\ \sigma_{v} &= -1.82 + 0.0221H \end{aligned} \tag{1}$$

Generally,the upper Carboniferous and upper Devonian strata outcropped within the limits of orebodies.The strata is divided from upper to lower,i.e.①Maping formation of upper Carboniferous(C_{3m}):purple and grayish purple argillaceous striped breccia limestone with purple mud stone;②Weining formation of middle Carboniferous(C_{2w}):grey middle-thick layer-like limestone with oolitic limestone;③Baizuo formation of lower Carboniferous(C_{1b}):grayish white,ecru and pinkish red middle-coarse-grained dolomite with light grey limestone; ④Datang formation of lower Carboniferous(C_{1d}):grey crypto-crystal limestone,a layer of 0.3～3.5m brown black fine siltstone and purple mud stone on bottom;⑤Third member of Zaige formation of upper Devonian(D_{3zg}^{3}):grey crypto-crystal limestone and yellowish white,pinkish red middle-grained dolomite.Qilinchang orebody occurred in the middle-lower of Baizuo formation of lower Carboniferous,whose strike was N12°～25°E, dip direction was SE and dip angle was 54°～65°

BASIC LAW OF ROCKBURST OCCURRING IN HUIZE LEAD-ZINC MINE

Rock Core Disking Phenomenon

The so called rock core disking phenomenon means that the rock core is broken into “disk” in the process of drilling.Generally,this phenomenon is seen in the igneous rock area,but it can be seen in the hard metamorphic rock and sedimentary rock also.Early in 1960s,this phenomenon was found.However,an adequate attention to it was paid in 1970s when it was regarded as a rock mechanics phenomenon which was unique in the high in-situ stress area.In addition,the rock core disking phenomenon was found in the construction of water power stations at Ertan,Lubuge and Laxiwa,including in Jinchuang mining area,in china.A different extent of rock core disking phenomenon in all strata was found in the process of drilling exploration of engineering geology at Qilinchang orebody in Huize lead-zinc mine.Through making a statistics of site drilling data,the result has shown that the rock core disking phenomena are characterized by:

- Wide distribution but less quantity.In all holes drilled in the construction,the disking phenomenon was seen in most of holes,but it was less in quantity,which means the disking was not serious.
- Rock disk was not thick,1～2cm on average,0.2～0.3cm for the thinnest and about 0.8cm in general.
- There was one type of rock cores unbroken into disk.The ring zone,which was clear and obvious on the rock core,was composed of staggered fine tooth-like fissures with about 0.5mm(max).This type of rock cores can be stripped into a disk along fissures,and then the disk can be connected to its original place.
- Generally,the rock disk was divided into two types of morphology:the one was uneven,the other was flat and smooth,whose surfaces were fresh,without any disseminated mark.

Rock disk produced in drilling and rock-core disked morphology are shown in Figures 1 – 2.

Fig. 1. Rock disk produced in drilling

Fig. 2. Rock-core disked morphology

Phenomenon of Schistose Scaling on Sidewalls of Drifts

A different extent of schistose scaling on the sidewalls of cross-cut drifts,which are located in Strata C_{3m},C_{2w} and C_{1b} as well as on Level 1571m of 10# orebody and Level 1751m of 1# orebody,was found,as shown in Figures 3 – 4. The most serious scaling occurred in Strata C_{2w}.The phenomena of scaling are characterized by:

- Generally,the scaling occurred in the hanging wall of orebody and strata C_{2w} near the adjoining boundary of Strata C_{2w} and Strata C_{3m}.
- The main rocks in the section of scaling were grey mud—fine-grained limestone.The scaling in Strata C_{2w} tended to be more serious when the parting mud stone in Strata C_{3m} got nearer from the adjoining boundary of Strata C_{2w} and strata C_{3m}.
- The scaling extended parallel to the sidewall of drift rounhly and about 22.0m(max) along the direction of drift.The thickness of rock slice on the break plane was 0.5～10cm.The scaling was a slate-like rock slice,whose medium thickness was equal approximately,and extended about 0.3～0.8m in the sidewall of drift.
- On Level 1764m of 1# orebody,the scaling occurred but was not serious.No scaling was found on Level 1764m above.On One side of break plane,many scaling occurred along the existent NW joints which were close and developed,especially in Strata C_{1b}.

Fig. 3. Side wall scaling in 1571m cross-cut drift

Fig. 4. Side wall scaling in 1751m cross-cut drift

TYPES AND STRENGTH CLASSIFICATION OF ROCKBURST

Types and strength classification of rockburst are the essential basis on which rockburst is predicted and controlled.In order to provide the basis for selecting a mining method and preventing rockburst occurring in the process of mining in future,the types and strength classification of rockburst resulting from the site investigation of engineering geology are provided:

- The first is to divide rockburst into a break loosening type according to an extent of rock fracture;The second is to divide rockburst into small size(0.5～10m long) and large size(10～20m long) according to rockburst range.
- Based on the failure pattern of rockmass where rockburst occurred,divide rockburst into a schistose scaling type.
- According to the genesis of high in-situ stress and the direction of maximal principal stress in rockmass where rockburst occurred,divide rockburst into a hybrid stress type.

Based on the specific stress conditions and rockburst characteristics,rockburst occurred,in general speaking,under the action of resultant stress;In the local stress concentration zone caused by soft and hard conditions of rock and at the location where the strata differed in hardness in hard and brittle Strata C2w, which contained the parting mud stone,adjacent to Strata C3m, this type of rockburst occurred,for the most part,on the side of hard and brittle parting layers,which was caused mainly by increasing of local stress in these hard and brittle parting layers approaching to the soft rock where a change in stress took place. Compared with many methods of rockburst strength classification,the rockburst strength takes slight or weak rockburst as main.

GENESIS AND MECHANISM OF ROCKBURST

Genetic conditions of rockburst

Factors having an impact on rockburst occurring are great many,for examples:rock strength,rockburst tendency of rock,water-retaining capacity of rock,geological structure,size and direction of in-situ stress field and so on.The following is the main factors having an impact on rockburst occurring in Huize lead-zinc mine.

Effects of in-situ stress field on rockburst

The hard rock in a high stress zone is capable of storing a greater elasticity and easy to accumulate a higher elastic strain energy.Chambers and tunnels are excavated in a high in-situ stress zone,which makes the stress around chamber and tunnel redistribute,whose stress can be up to 2～3 times higher than initial in-situ stress.The calculated result showed that stress concentration factor and maximum stress around cross-cut drift in Strata C_{2w} on Level 1571m were about 2.0 and 59.71MPa respectively.The existing stress-measured data about the world rockburst engineering can be divided into two classes:The one is the maximal principal stress around chambers,the other is the maximal principal stress in in-situ rock.This is two different physical concepts,but there is a certain relation between them.Based on the statistical analysis of existing data,the ratio of maximal principal stress around chamber to uniaxial compressive strength of rock is related to rockburst,as shown in Table 1.

Table 1. Relation of rockburst strength with main factors

Index	Rockburst			
	No	Weak	Medium	Intense
σ_θ/R_c	< 0.3	0.3-0.5	0.5-0.7	> 0.7

Generally,rockburst or rock core disking can occur at $R_c/\sigma_1=3\sim6$.A serious rockburst could occur at $R_c/\sigma_1<3$.For example: $R_c/\sigma_1<4$ and $R_c/\sigma_1=4\sim7$ are listed at highest and high stress zone respectively in China National Standards GB50218-94(BQ classification).When stress reduction coefficient is consideded in BQ Classification System, $R_c/\sigma_1=2.5\sim5.0$ and $R_t/\sigma_1=0.16\sim0.33$ are listed at possible slight rockburst. $R_c/\sigma_1<2.5$ and $R_t/\sigma_1<0.16$ are listed at possible serious rockburst.Based on results obtained from tests and calculation,parameters of $1^{\#}$ orebody related to rockburst are shown in Table 2.

Table 2. Parameters of 1# orebody related to rockburst

Mining Levels	R_c/σ_1	R_t/σ_1	σ_θ/R_c	Strata	Depth (m)
Level 1944m	7.33	0.37	0.27	C_{2w}	419
	7.52	0.38	0.265	C_{1b}	
Level 1844m	4.17	0.21	0.43	C_{2w}	514
	4.28	0.22	0.42	C_{1b}	
Level 1764m	2.83	0.14	0.52	C_{2w}	636
	2.93	0.15	0.49	C_{1b}	

Note: σ_θ was derived from the result obtained from finite element calculation.

The previous results have shown that there is possibility of rockburst indeed in strata,under the action of in-situ stress,in the mining area,This is the in-situ condition making rockburst occur.

Effects of geological structure/rockmass structure/rock property on rockburst

Under the condition of same initial in-situ stress,rockburst occurring and its serious extent are dependent on the brittle and elastic deformation properties of rock.Only in brittle and hard rockmass,which is fresh and complete but hard and compact,can local rupture rock block obtain a function which is adequate to make rockburst occur and release abruptly,under the action of a certain level of stress.In usual case,igneous rock whose uniaxial compressive strength (R_c) is > 150 MPa or sedimentary rock (R_c > 50 MPa) tends towards rockburst.The statistic relation of W_{et} (elastic deformability index of rock) and K_u (brittleness coefficient of deformation) with rockburst strength is shown in Table 3.C_{2w} host rock locating at the hanging wall of 10# orebody was argillaceous network-like limestone with oolite,whose stress-strain curve,on the whole,was characterized by Ⅰ—shape curve,and its Rc,Wet and Ku were 39.94～76.87MPa (54.24MPa on average) ,3.17 and 4.48 respectively,with a tendency towards weak rockburst.The activity of rockburst in argillaceous limestone was rare in the world.It was reported that slight and middle-sized rockburst subsequently occurred several times in the sandy mud stone in Erlang Mountain highway tunnel,Sichuan—Xizang highway in China.The said rockburst occurred mainly in the form of heavy scaling of rock around tunnel.

Table 3. Statistic relation of W_{et} and K_u with rockburst

Index	rockburst			
	No	Weak	Medium	Intense
W_{et}	< 2.0	2.0～3.5	3.5～5.0	> 5.0
K_u	< 2.0	2.0～6.0	6.0～9.0	> 9.0
R_c/R_t	< 14.5	26.7～14.5	40～26.7	> 40

Parameters of all strata at 1# orebody related to rockburst are shown in Table 4.

Table 4. Parameters of all strata 1# orebody related to rockburst

	C_{2w}	Oxidiz-ed ore	Sulphi-de ore	Mid coarse dolomite	Fine dolomite	C_{1d}	D_{3zg}
R_c	81.4	39.9	62.96	53.8	83.45	66.6	87.2
R_t	4.11	2.85	2.88	1.97	4.20	2.69	2.85
R_c/R_t	19.8	14.0	21.86	27.3	19.87	24.8	30.6
W_{et}	3.17	2.01	1.86	1.80	4.08	2.74	2.28
K_u	4.49	6.05	4.46	5.27	5.99	6.64	4.46

Based on analysis of results from the rock mechanics tests,the strata,with the exception of oxidized ore,meet the conditions of slight rockburst;Except that lithological condition has been described above,the completeness of rock has a great impact on whether rockburst occurs.In the site investigation and drilling exploration of engineering geology,it has been discovered that joints and fissures in C_{2w} of hanging wall were less developed,whose R.Q.D was >70% in general,so this rockmass belongs to being more complete.

Effects of mining depth on rockburst

The extent of in-situ stress is one of factors having an impact on occurring of rockburst.Meanwhile,mining depth is related to in-situ stress closely.Therefore,mining depth is a factor,which is not ignorable,having an impact on occurring of rockburst also.For example:When the engineering geology assessment of 6#/8# orebody in Huize lead-zinc mine was made,the disking phenomenon of rock core in the drill holes for the engineering geology exploration was found also.However,during the site investigation of engineering geology,the scaling phenomenon of sidewalls in cross-cut drift was not found.The depth of 8# orebody on Level 1571m was about 650m,and the in-situ stress along strata strike was about 21.0MPa.The depth of 10# orebody on Level 1571m was about 920m,and the in-situ stress along strata strike was about 28.0MPa.8# and 10# orebodies lay in the same hanging wall of Qilinchang reversed fault,whose geological conditions were similar,but there was a phenomenon of rockburst occurring in 10# orebody.As shown in Table 2,the depth of 1# orebody on Level 1764m was about 650m,where a phenomenon of slight scaling began to occur.Therefore,mining depth is an important factor having an impact on occurring of rockburst also.In general speaking,no matter where either in metals mines under the condition of hard rock mining or in coal mines,there is a critical depth at which rockburst will occur.Some scholars presented a formula for predicting the critical depth of rockburst.Nor is this all,many mining practice have proved that quantity and frequency of rockburst and the loss caused by it increase with increase of mining depth.With the development of deep orebody mining in Huize lead-zinc mine,the depth of mining will increase gradually and the harm from rockburst would be more serious.However,under the concrete condition of engineering geology in Huize lead-zinc mine,the relation of rockburst occurring with depth needs to be studied further.

Mechanism of rockburst

After a drift was excavated,the local stress concentration occurred within the certain limits of drift periphery,and the principal stress trajectory ran parallel to the drift wall basically;The tangential stress σ_θ at drift periphery was higher than σ_1,but the normal stress σ_r was very low,even equaled 0.Therefore,the rock at drift periphery was in the state of uniaxially compressed or low confined brittle-failure.According to the results of uniaxial compression test of rock,it can be known that the fracture of rock specimen in the state of brittle failure was divided into two patterns:The one was tensile crack,characterized by the parallel of crack plane to the acting direction of σ_1,the other was the inclined shearing plane.Their failure characteristics were corresponding to those of both split-loosening type and tensile-shear shooting type rockburst.The uniaxial compression tests,which all kinds of rock from Huize lead-zinc mine were compressed by INSTRON rigid press,showed that most of rock produced tensile crack after uniaxial compression.

Also,the results of site investigation showed that the rockmass of hanging wall,under the condition of in-situ stress level in the mining area,took tensile crack as main;The failure characteristics of rockburst in the mining area should belong to a brittle and unstable breaking equilibrium loss which occurred under the condition of lower stress level,i.e.belonging to a split failure.The principal stress trajectory around drift ran parallel to the drift wall basically,so a group of tensile crack planes roughly parallel to the drift wall produced to form a group of similar slate-like rock slice.Undre the action of tangential stress σ_θ,rock slice was flexed and broken,or the edge of rock slice produced a local inclined-shearing break,to form the split-loosening type rockburst.Obviously,both the characteristics of rockburst occurring in the site and the results of rock tests in the laboratory showed that the brittle failure of host rock was a deciding factor of the characteristics of rockburst failure.It is worthy of emphasizing that all sections,where the scaling was more serious,in Strata C_{2w} of hanging wall were Strata C_{2w} close to the parting mud stone in Strata C_{3m};And the sections where the fine-grained dolomite in Strata C_{1b} in $1^{\#}$ orebody produced some scaling are always ones where the fractured cleavages in NW direction were closed and developed.The geological structure has an important impact on the extent of scaling:The one is the thickness of the parting mud stone in strata C_{3m} was great (about 8.0m),the other is the existence of the parting mud stone in Strata C_{3m} caused the rock of hanging wall to produce and increase the local stress.Therefore,rockburst occurred always on the side of hard and brittle parting layer at the time of drifting to the place where rock changed in hardness and softness,which was caused by the change of soft rock stress to make its near parting layers which were hard and brittle increase the local stress.The knowledge of this law can be used as important geological basis of predicting and preventing the rockburst in the process of drift excavating in the mining area.

CONCLUSIONS

According to the results of geological exploration at present,the orebody in Huize lead-zinc mine extended down more than 250m from Level 1571m,and the in-situ stress will certainly increase with further increase of mining depth.Meanwhile,all existing drifts are only used for the geological exploration.No matter what mining method is used,the stress redistribution can be produced in the stopes and the host rock of hanging wall and foot wall in the futural mining of deep orebody.The harm of rockburst will be more obvious,under the condition of much higher stress level.When the mining method of deep orebody is designed,therefore,the mining method and stoping sequence used should be considered adequately and the higher stress concentration should be avoided as possible to prevent a large-size rockburst.

REFERENCES

Xu L.S. and L.S. Wang [2000]. “Study on The Rockburst Type Classification,” Journal of Geological and Environment Preservation, Vol.11,No.3, pp. 245 – 247.

Xu L.S.and L.S. Wang [1999]. “Study on The Laws of Rockburst and its Forecasting in the Tunnel of Erlang Mountain Road,” Chinese Journal of Geotechnical Engineering, Vol.10, No.5, pp. 143 – 146.

Yang, T. and G.W. Li [2000]. “Study on Rockburst Prediction Method Based on The Prior Knowledge,” Chinese Journal of Rock Mechanics and Engineering, Vol.19, No.4, pp. 429 – 431.