

Typical Geo-Hazards and Countermeasures of Mines in Yunnan Province, Southwest China

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Abstract. Mining-induced geo-hazards have caused enormous destruction and threat to mines. Known as the "kingdom of nonferrous metals" and located in Southwest China, Yunnan Province developed mining-induced geo-hazards well with characteristics of multiple types, widespread distribution and serious damage. Landslides and debris flows are two common sub-types of geo-hazards causing most serious damage in Yunnan, and some of them were very representative in the world. Two landslides and two debris flows were chosen to analyze deeply. Both Laojinshan Landslide and Sunjiaqing Landslide possess the characteristic of rock avalanches. The high sliding speed and long distance made the landslides translate into clastic flows with impact force and caused enormous destruction. Rainstorm and mining waste rock were two main factors to induce debris flows in Yunnan mines. Heishan valley debris flow of Dongchuan copper mine was a super large rainstorm type viscose debris flow with very low frequency, which brought a good caution to utilize valleys which looked an unlikely debris flow. Nandagou Valley of Jinding lead-zinc mine in Lanping County was a rainstorm stimulating, gully-type, high frequency and large scale debris flow, which was induced by mining activities. Many countermeasures have been used for Yunnan mines, including engineering treatment technology and ecological remediation, monitoring and forecasting, relocation and public administration.

1. Introduction

Mine geo-hazards are disasters caused by the destruction of geological environment resulting from human mining activity and natural geological activity [1], including rockfall, landslides, debris flow, ground collapse, ground fissures and land subsidence and so on. Mine geo-hazards have not only caused destruction and threat to mining area but also people's production and living safety around some mining areas. The effective prediction and management of mining-induced geo-hazards is of great importance to the mining industry [2].

In China, mine geo-hazards develop well with feature of various type, widespread distribution, great influence and serious damage [1]. Known as the "kingdom of nonferrous metals" and located in Southwest China (Fig.1), Yunnan is one of the most complicated and serious provinces with mining-induced environmental problems, especially geo-hazards [3].

The objectives of this study were (i) to summarize main characteristics of mine geo-hazards; (ii) to analyse the features and genesis of representative mine geological hazards and (iii) to present some countermeasures for mine geo-hazards in Yunnan Province.



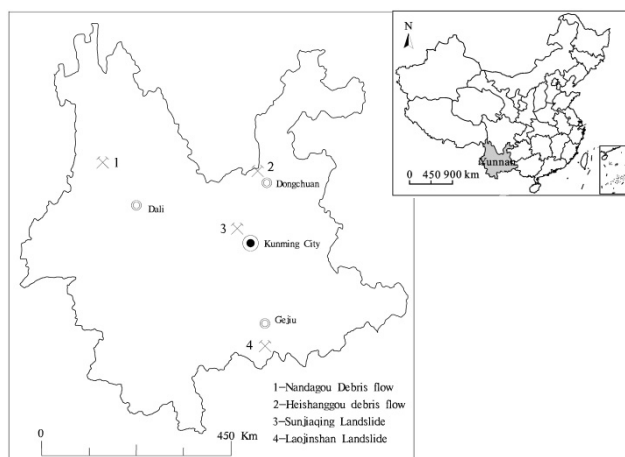


Figure 1. The location of mines with typical geo-hazards in Yunnan

2. Main characteristics of mining-induced geo-hazards in Yunnan

(1) Multiple types and widespread distributions

At present, there are about 150 at scale mines suffering from geo-hazards in Yunnan province, which can be divided into 7 sub-types including landslide, collapse, debris flow, surface collapse, ground subsidence, ground fissure and water bursting. According to incomplete statistics, up to the end of 2002, there were 171 landslides, 56 collapses, 78 debris flows, 169 surface collapses and 41 water bursting, which distributed widely in mines of Yunnan [4].

(2) Serious damage

Mine geo-hazards have caused grievous death toll and financial loss in Yunnan. From 1950 to 2005, roughly 1212 deaths and 533.34 million Yuan RMB direct losses were caused by mine geo-hazards [1], in which landslides and debris flows are two most serious sub-types.

Single large scale disaster geological hazards happened occasionally in mines, and only mega-disasters caused 937 deaths, accounting for 77.3%. Causal types mainly were collapse, landslide and debris flow, yet the small and medium-sized of them also caused mega-disasters (Table 1). So, effective preventive measures to keep away from mega-disasters are the key of the disaster prevention and mitigation.

Table 1. List of mega-disasters caused by mine geological hazards since 1949 [1]

location	time	type	scale	death
Jinchang gold mine, Yuanjiang county	May, 1995	collapse	medium	43
Yinmin dressing plant of Dongchuan copper mine	1978; July 9 th , 2001	landslide	medium	49
Laojinshan gold mine, Yuanyang county	May 31 st and June 3 rd , 1996	landslide	medium	372
Jinshachang Pb-Zn mine, Yongshan county	June 29 th , 1990	debris flow	large	52
Liudu copper mine, Qiubei county	1990	debris flow	small	30
Heishan valley of Dongchuan copper mine	May 27 th , 1984	debris flow	large	121
Huogudu tailing pond, Gejiu City	September 23 rd , 1965	debris flow	large	171

(3) Seasonality, group-occurring and often forming disaster chain

Mine geo-hazards occurred seasonally and group-occurring in Yunnan, and often formed disaster chain. The precipitation influences were very obvious. Most of mine geological hazards occurred between May

to October in accordance with the rainy season of Yunnan, in which rainfall accounts for 85-95% of annual precipitation, averaged 1100 mm. Heavy rainfall was often direct factor to induce geological disaster. Geo-hazards could occur simultaneously in and around mining area with evident group-occurring characteristic because of large area of rainfall, especially in large and old mining area such as Dongchuan copper mine and Gejiu tin mine.

(4) Complex genesis and recidivity on the spot

Most geological environment conditions of mines in Yunnan were fragile, which were restricted by integrated factors such as weather, landform, formation lithology, geological structure, groundwater and earthquake. Genesis of geo-hazards was often multivariate and intense human engineering activity should not been a noticeable factor [3]. There was still considerable controversy for genesis of some mine geo-hazards until now. It is a remarkable fact that many mine geo-hazards would occur on the spot again and again [5].

3. Typical Landslides

Landslides are one of the most common mining-induced Geo-hazards in Yunnan Province [3]. In general, there are three kinds of mining activities to induce landslide disaster [4]. The first is induced by the improper cutting slope of open-pit mining slope; the second is induced by the goaf area deformation, and the third is induced by improper stack of mining dregs. The features of landslides in Yunnan mines included high frequency of occurrence, great damage, many casualties and terrible financial loss. Laojinshan Landslide and Sunjiaqing Landslide were typical examples.

3.1 Landslide of Laojinshan gold mine in Yuanyang County

Laojinshan gold mine is located at E 103°08' and N 22°51' in Yuanyang country. Laojinshan Landslide, one of the most disastrous Landslides in China in 20th century [6], occurred in the mass mining area of Laojinshan gold mine at the same place on May 31st and June 3rd in 1996 in succession. It led to 148 deaths, 224 disappearances and 146 serious injuries [7]. In addition, the direct financial loss was as high as 160 million Yuan RMB.

The source area of Laojinshan Landslide was about $2.3 \times 10^4 \text{ m}^2$ with 150-180 m length and 120-200 m width [6]. The maximum thickness of slip mass was 25 m. The total volume of two landslides was about $4.3 \times 10^5 \text{ m}^3$ [4]. The material of slide resource was middle to intensive weathering dolomite of S_2 (Fig.2). The longest sliding distance of landslide material was 1600 m with 880 m of vertical slip. The whole process of Laojinshan Landslide included steps of start-slide-disassembly-debris flow in less than one minute [8]. According to the above features, Laojinshan Landslide belonged to high position, high speed, large scale, long distance, middle to deep basement weathering belt, collapse type landslide to debris flow.

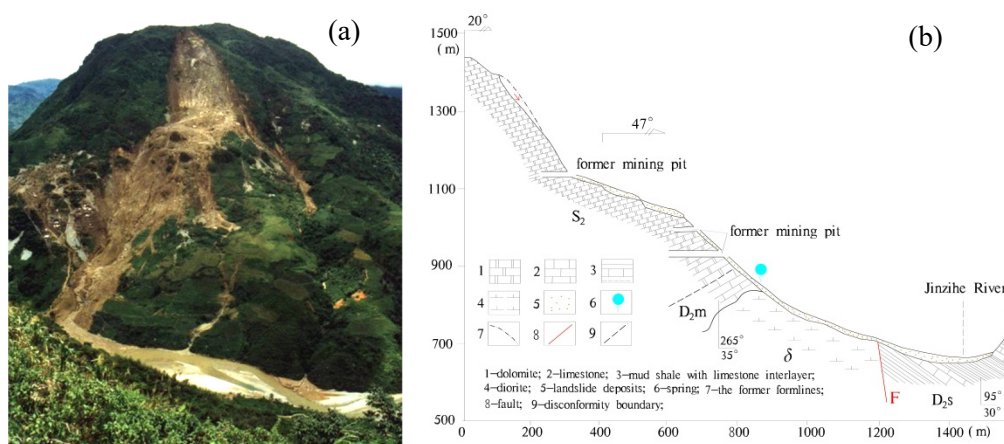


Figure 2. Photo and sectional drawing of Laojinshan Landslide [7, 8]

Many factors led to the landslide mega-disaster. The basic condition was composed of precipitous landform and rock mass structure, while the inducing factors mainly included heavy rain before the landslide and intensive mining activates. The former landform of sliding resource area was raised and like an eagle's mouth, so unloading separation fractures may form easily in the slope shoulder. The dolomite in sliding resource area was middle to intensive weathering with stratiform cracked structure. Three groups' joints developed with strike 310° - 340° , 25° - 45° , 70° - 85° . The joints with strike 310° - 340° were areal tectonic joint and developed very well with dip 55° - 66° , which extended several to tens of meters with 3-5 per meter of linear density. In fact, the joints controlled the landslide and developed into major slipping plane [8]. Heavy rain was an important natural factor to induce Laojinshan Landslide. According to data from weather bureau of Yuanyang County, total rainfall in the landslide area was 137 mm in four days from May 27th to 30th. Intensive mining activity was indispensable man-made factor to destroy stability of the mountain. There were 144 mining pits with more than 120 kilometers of total length in the mass mining area of Laojinshan gold mine [6].

3.2 Landslide of Sunjiaqing quarry in Kunming City

Landslide of Sunjiaqing quarry occurred in Xishan District of Kunming City on February 21st, 1990. The landslide caused 25 workers disappeared, national road of 180 meters destroyed, two cars and one bulldozer buried [9]. Mining activity of Sunjiaqing quarry began in 1957. Artificial slope of 30-40 meters high, 100 meters long and 60 meters wide had been formed before the landslide occurring. Z_2d light grey and pale yellow quartz sandstone with cracked structure was exploration object, which was also landslide mass.

Sunjiaqing Landslide was a middle scale, tractive, deep-bed, weathered bedrock and bedding landslide. The total affected area was about 53 800 m² and the deposits volume was 250000 m³ [9]. The landslide was composed of slipping area and deposit area. The perimeter of slipping area was 380 meters, while the area was 8300 m². The boundary of slip area was scarp of 5-40 meters high. Shear outlet of the landslide composed its eastern boundary, which trended into 85° ~ 95° with dip angle of 35° ~ 45° . Most slip area was covered by clastics from trailing edge, and average thickness was 9 meters. Main landslide mass was about 120 meters long and 50~60 meters wide. Deposit area distributed in east to shear outlet of the landslide, and landslide mass was mainly separated from sliding surface. The deposits were composed of principal deposits and dispersal deposits with total 176000 m³.

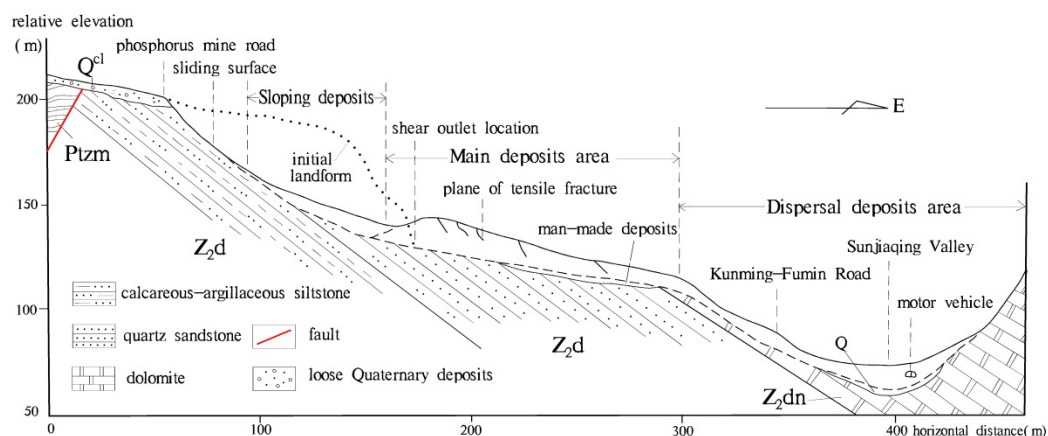


Fig. 3 Longitudinal section of Sunjiaqing quarry Landslide [9]

The overall process of Sunjiaqing Landslide could be divided into three moving stages, namely slipping-leaping-clastic flowing, and air cushion effect was evident in the moving process of the landslide [10]. The maximum distance of slipping mass was 600 m with altitude distance of 145m. Some of clastic flow mixture of airflow and clastic continued to move northward along Sunjiaqing Valley, and the farthest distance was 200 m.

The landslide formation was induced by man-made unreasonable excavation without additional factors such as rainfall, earthquake and load. There was weak structural belt between upper quartz sandstone and lower calcareous-argillaceous siltstone, which became the sliding surface (Fig.3). According to sampling test, peak strength (c) of the weak belt was only 90-450KPa, which was much less than other part, namely 9,590 – 38,000 KPa [9].

4. Typical debris flow

According to incomplete statistics, most of 78 debris flows in mines of Yunnan were small scale, accounting for 75.6% [4]. Based on genesis, rainstorm type and dam break of tailings pond type were two types of debris flows. 90.3% of debris flows were related to mining waste rock which was main source. However, some valleys in mining areas looked an unlikely debris flow valley, and they were used for important installation even living quarters. Heishan valley debris flow and Nandagou Valley debris flow were very representative.

4.1 Heishan valley debris flow of Dongchuan copper mine

4.1.1 Characteristics of debris flows in Dongchuan mining area

The Dongchuan ore field is the third largest copper mining area in China with more than 2000 years mining history, extending over an area of about 660 km² (E 102°41'-102°51', N 26°8'-26°30') around Dongchuan city, about 120 km north of Kunming. Debris flow disasters occur frequently due to completely destroyed ecological environment and degenerated ecological functions by the long-term copper mine mining and refining in Dongchuan, especially concentrically distributing in drainage basin of Xiaojiang River, where is known as "Debris flow museum in the world" [11].

4.1.2 Characteristics of Heishan valley debris flow

Heishan valley debris flow was one of the most disastrous mine debris flows in China. The most serious debris flow occurred in Heishan valley of Yinmin Town in the morning of May 27th in 1984, which caused 121 deaths, 34 injuries, 13 million Yuan direct loss and 14 days production halts of Yinmin Mine [12]. It was a super large rainstorm type viscose debris flow with the flow velocity of 6.3 m/s and discharge of 350m³/s.

Some characteristics were summarized as:

- (1) It occurred suddenly with very low frequency. There was no portent before the occurrence of Heishan valley debris flow when the runoff was only 0.13 m³/s. It never occurred in recent one hundred years according to investigations.
- (2) It occurred in a short time with huge deposits. Catchment area of debris flow formation region is only 8.27 km². In less than one hour, the total deposits was as much as 210 thousand m³ with maximum discharge of 350 m³/s, while the maximum flood peak discharge by actual measurement was less than 4 m³/s [12,13]. Maximum surge of debris flow was only once within several minutes.
- (3) Debris flow was viscous with very strong suspension force. The volume-weight was 2.2 t/m³. The size of the largest stone carried by Heishan valley debris flow was 5.5m×3.3m×1.6m, of which motion distance was about 900m, while other stones were carried farther [14].

4.1.3 Genesis of Heishan valley debris flow

The debris flow was induced by extraordinary rainstorm. According to Luoxue meteorological station of 7.5km away, it sprinkled in May 22nd and 23rd, then a heavy rain of 27.1mm fell in May 25th. A light rain of 2.5mm sprinkled again in May 26nd. It continued to rain for one hour from 4:30 in May 27th with 17.3mm rainfall accompanying hail of 10mm diameter. According to survey of local residents, the rainstorm continued for approximate 20 minutes and surface water was impounded, then the debris flow occurred. The estimated rainfall intensity was about 120mm per hour.

Solid material resource of the debris flow was mainly from proluvial and alluvial deposits in bed of Heishan valley, which were composed of dimension stone, gravel, sand and clay. The thickness of deposits was 3-5m, and the total volume was about 300 thousand m³. Surface layer was comprised of

coarse gravel, and the lower was relatively fine mixture. There were few landslides along Heishan valley. The mechanism was restart of deposits in bed of Heishan valley induced by extraordinary rainstorm in the favorable valley vertical gradient of 18.76%.

4.2 Nandagou Valley debris flow of Jinding lead-zinc mine in Lanping County

As the largest Zn–Pb deposit in China, the Jinding Zn–Pb deposit is located in Lanping County. Covering a surface area of about 8 km², the deposit has a reserve of ~200 Mt ore grading 6.08% Zn and 1.29% Pb, i.e., a metal reserve of 15 ~Mt [15]. In 1980s, there were more than 100 underground pits due to the unauthorized and wasteful mining by the crowds. Since 1990s, the local government had reorganized Jinding mining order, and the opencast working became the major development method. Geological environment of Jinding mining area was destroyed seriously because of long-term mining activity. Nandagou Valley debris flow has caused many disasters, including 24 deaths, 6 injuries and 15 million Yuan RMB direct losses. In addition, Bijiang River, an important first grade tributary flowing of Mekong River, was cutoff by the debris flow for 9 times.

During rainy season of 2000, Nandagou Valley debris flow occurred for 17 times. The most disaster occurred on August 18th, which caused 10 deaths, 5 disappearances and 1 serious injury. The debris flow occurred again next day, which caused 2 deaths and 4 serious injuries. The debris flow occurred once more on August 29th, which caused 2 deaths and 1 serious injury. On September 9th, a large scale mining waste slag type landslide occurred in the middle reach of Nandagou Valley, and the slipping materials became a barrier dam. Subsequently, the dam broken and another debris flow occurred, which stopped Bijiang River up.

Nandagou Valley, located in left bank of Bijiang River, was 3800m long and 15~30 m wide with average (Fig.4). The drainage area was 3.77 Km². There was permanent flow of 1.29~2432 m³/d. The debris flow formation region was 3.66 km². The length of flowing area was about 800m with width of 30-60m and longitudinal grade of 90%. The thickness of loosen deposits at the bottom of Nandagou Valley was 3-6m. The Valley always showed as a braided stream. The accumulation area was located in stream outlet of Nandagou Valley, covering 8.1 ×10⁴ m².



Figure 4. Photo of Nandagou Valley debris flow

Slurry density of Nandagou Valley debris flow was 1.59g/cm³. There were some characteristics for the debris flow of ultimately flowing to accumulation area, namely existing debris flow head of 1m, big

viscosity (slurry density $> 1.5 \text{ g/cm}^3$), long time of duration (5-15 minutes), strong carrying capacity at a time (maximum about $1 \times 10^4 \text{ m}^3$) and fast flowing speed (about 10 m/s). In a word, Nandagou Valley was a rainstorm stimulating, gully-type, high frequency and large scale debris flow, which was induced by mining activities.

The genesis of Nandagou Valley debris flow could have been concluded three factors as follows:

(1) Loosen deposits resource condition

Barren rocks, approximate $112 \times 10^4 \text{ m}^3$, were widely discharged on both sides of Nandagou Valley, which often developed into landslides and became major resource of the debris flow [16]. In addition, the strata in Nandagou Valley drainage basin were clastic rocks of lower cretaceous and middle Jurassic Series, which were fragmentized and could be easily eroded by water.

(2) Water resource condition

The annual average rainfall is 1088 mm, and maximum daily precipitation is 100.2 mm. Rainy season is from June to October, accounting for 74% of annual precipitation. The maximum of rain-lasting days can continue for more than 40 days. Rapid rain was the induced factor for the debris flow. Rain converged quickly into Nandagou Valley and water flow changed fast and huge. The debris flow induced by $20 \text{ mm} \pm$ daily precipitation could get to deposited fan and block Bijiang River. Debris flow was also able to occur induced by 15 mm daily precipitation, but it would stop in flowing area and could not get to deposited fan.

(3) Topographic condition

Main gully of Nandagou Valley was 3.8 km long with average longitudinal grade of 7.9%, and the drainage area was 3.77 km^2 with watershed integrity coefficient of 0.52. These topographic conditions added "V" type valley and bank slope of 30° - 40° fit debris flow [17].

5. Countermeasures

5.1 Engineering treatment technology and ecological remediation

In light of the characteristics of different mine induced geo-hazards, different engineering treatment technologies should be adopted [3]. For example, a series of engineering treatment technologies has been adopted to control debris flow in Dongchuan copper mine, Gejiu tin mine and Lanping lead-zinc mine, such as guide trenches, retaining dams and multiple check dams. Systematic investigation and prevention engineering were done for Nandagou debris flow in Lanping lead-zinc mine since 2001, including six retaining dams, ten check dams and four strengthening riverbed dams.

5.2 Monitoring and forecasting

Automatic displacement deformation monitoring and alarming systems have been established in many mines in Yunnan, such as Suoyipo unstable rock in Dongchuan copper mine and Buzhaoba open pit of Xiaolongtan coal mine [18]. Deep hole displacement monitoring technique was applied in landslide survey for searching sliding position in the open pit of Lvhe coal mine [19].

5.3 Relocation

Geo-hazards induced mining activities not only bring serious harm to mine itself, but also make the nearby towns, villages and other infrastructure suffer huge losses. In case of difficulty and too high cost for control project, relocation is the best way to avoid geo-hazards. Many towns and countries have been relocated, such as Kafang Town in Gejiu City and Yinmin Town in Dongchuan City.

5.4 Public administration

(1) To solve the mine environment problems left over by history step by step

Most of seriously developing geo-hazards mines are large and medium-sized mines with long term history and state-owned, which have made contribution to the development of national economy without enough environmental protection investment. At present, mining enterprises are faced with poor

economic benefit and many environmental issues. So it is necessary for government to play a leading role to solve the mine environment problems left over by history step by step.

(2) To improve the new mine access requirements

To extract experience and draw a lesson from past mining history, it is necessary to be strict to examine and approve new mines. On the stage of project feasibility study, geological hazards risk should be evaluated strictly, so is environmental impact.

(3) To carry out margin system of mine geological environment restoration

It is necessary to implement margin system of mine geological environment restoration strictly and guarantee the margin to recover mine geological environment. The system can prompt mine enterprise to take environmental investment into account and reduce destruction of mine geological environment to minimum.

6. Conclusion

(1) Geo-hazards developed well in mines of Yunnan Province with characteristics of multiple types, widespread distribution and serious damage. What is more, they often occurred in groups and formed disaster chain in rainy season.

(2) Landslides and debris flows are two common sub-types of geo-hazards causing most serious damages in Yunnan. Landslide of Laojinshan gold mine in Yuanyang County was one of the most disastrous Landslides in China in 20th century, while Heishan valley debris flow of Dongchuan copper mine was one of the most disastrous mine debris flows in China.

(3) Both Laojinshan Landslide and Sunjiaqing Landslide possess the characteristic of rock avalanches. The high sliding speed and long distance made landslides translate into clastic flows with impact force and caused enormous destruction.

(4) Rainstorm and mining waste rock were two main factors to induce debris flows in Yunnan mines. Heishan valley debris flow of Dongchuan copper mine was a super large rainstorm type viscose debris flow with very low frequency, which brought a good caution to utilize valleys looked an unlikely debris flow. Nandagou Valley of Jinding lead-zinc mine in Lanping County was a rainstorm stimulating, gully-type, high frequency and large scale debris flow, which was induced by mining activities.

(5) According to various geo-hazards in different mines, appropriate countermeasures should be chosen to prevent and control mine geo-hazards. In Yunnan, many countermeasures have been used, including engineering treatment technology and ecological remediation, monitoring and forecasting, relocation and public administration.

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