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Problems of Mud Solid Intrusions into Mining Pits

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Abstract

It often happens that mud solids intruded into mining pits, which affects safety, causes great damage to mining operation, and deteriorates working conditions. In this paper a classification of intruded mud solids is given, with some case histories of intrusions of karst-cave mud and loose materials, and rock burst in coal mines in China. The mechanism of mud solid intrusions is theoretically studied from hydrogeology and engineering geology. It is closely related to the geological structure, mode of ground water flow, lithology, physical properties of rock, action of water and rock, mining depth and the crustal stress. Effective methods for forecast and prevention of the mud solid intrusions are put forward.

Examples of Mud Solid Intrusions into Mining Pits

With the development of scientific researches on coal, a series of phenomena of engineering geology and hydrogeology in

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mining pits have been found, such as the intrusions of coal, rock, loose materials and karst-cave mud into mining pits. The sudden emergence of lumps of coal and rock was due to the sudden release of geological stress and additive stress from voids in mine, which strongly extruded rock formation. Besides the intrusions of coal and rock, these phenomena consist of the shakes of shaft, shock wave and the rapid deformation of wall rock. The phenomena are called "Sudden Release of Stress", being abbreviated to "SRS". SRS is also a dynamic engineering geology phenomenon with strong destruction, which exerted from the release of deformation energy when gallery and wall rock of the mines were out of balance.

142 SRS happened in six mining areas in Jingxi from 1955 to 1980, which destroyed openings of 5,400 meters and 110 houses. One, happened in Mentougou Mine, caused the shock of the Richter scale of 3.81, and the epicentral intensity of 7^{0}, which was the strongest in China on record. Another happened in the pipeline (-412 m) in Xinzhuangzi mining area of Huainan, from which 1,090 tons of coal, sandstone and mudstone intruded into the openings for over 100 meters, 4.94 meters from the rock burst place standing a lump of sandstone of 2.85 tons, that caused heavy losses to the engineering of shaft extension. 41 SRS occured successively in Datong mining area with the shock of the Richter scale of 2 - 3, which did great harm to personal safety and production (Table 1). According to the incomplete statistics, nearly 400 SRS on record happened in China in the past 30 years. These problems also occured abroad. Hundreds of SRS happened in Poland in the past 20 years before 1970, which destroyed 27,550 meters of openings. Strong shocks caused by SRS in the Prowance Mine in France emerged storm wind, just as that happened in the Wajienwan Mine in China. In some places where SRS happened, over one hundred tons of coal were thrown, which got obvious scratches on the roof by the strong projecting forces; and floor heavings occured in some places, that their shock signals could be received by the seismic recorders tens kilometers away. From above, it can be seen that destruction for openings by the sudden release of crustal stress has the generality at home and abroad.

Table 1. Typical Examples of Different Solid Material Intrusions into Mining Pits

Types of intrusions	Names of mining bureaus and mining areas	Time of intrusions	Features and harmness of solid intrusions	Causes of intrusions	Note
Examples of coal and rock intrusions	Jingxi Changgouyu Daanshan		Rock burst, which destroyed openings of 5,400 m in total, harmful to production.	Sudden release of stress	SRS occured in the mining areas, such as Mentougou, Datai, Taozhuang, Taiji, Shengli, Longfeng, Tianchi, Beipiao, Helu, etc. On Erchao Bank in Mentougou mining area, SRS occured in Aug.,1979, with shocks of the Richter scale of 3.18, and the epicentral intensity of 7, which was the strongest in mines of China.
	Datong Wajienwan		At the time of mining for Seam No.14, the worked-out section was up to 160,000 m^2, thus storm wind caused by SRS destroyed 11 under-mine ducts, blew down 1 loaded car and blew off supports of 90 m, which did great harm to ventilation and haulage systems. Production was stopped.	Sudden release of stress and the additive worked-out stress	
	Kailun Tangshan	1978	SRS happened in succession, by which openings of 5,950 m were damaged once in the Bank No.5275.	Sudden release of stress	
	Huainan Xinzhuangzi	1980	Following sudden release of stress, intruded lumps of coal and rock of 1,250 tons, that covered the rock loader (which was 2 m in height) and stopped up the openings for more than 100 m, causing great losses.	" "	Among the intruded rock, the largest one,with the diameter of 1.2 m and the weight of 2.85 tons, was thrown out 50 m from the rock burst place. Underground water inrush occured later.
Examples of loose layer intrusions	Kailun Tangshan	1924	Sand, rock and clay mixture intruded into shaft, by which Cross-cut No.13 was collapsed and stopped up for 76.25 m, and Cross-cut No.14 106.75 m. The ground was sunk down, forming a huge hollow of 6,000 m^3.	With the seam dipping 60 - 70°, thickness 5 - 9 m, coal pillars 24.4 m, bump occured when mining for the pillars were not large enough, causing intrusion.	Eight times of accidents similar to this happened before 1949, all of which were due to the pillars on the small side.
	Xuzhou Xinhe	1965	Loose layers intruded into shaft from the Opening No.502, with sand, rock and mud of 6,400 m^3, which stopped up the opening for more than 1,200 m. The ground was formed a huge hollow of 200X80 m.	When mining for the sharp dipping Seam B, the coal pillar (31 meters thick), which was mined, exceeding the mining limit, was broke through by water, mud, sand and rock, with the debris flow of 5 m/min.	A water pump on the bank was moved with the sand-rock-mud flow for over 1,000 m.
	Xinwen Huangnigou	1961	The shaft was submerged by the intrusions of water and mud. A pit, 10 m in diameter and 1m in depth, was emerged from the ground.	Bump range touched the alluvial sandy beach of the Xiaozi River.	A test of mining with movable-filling before mine abandonment.

Types of intrusions	Names of mining bureaus and mining areas	Time of intrusions	Features and harmness of solid intrusions	Causes of intrusions	Note
Examples of loose layer intrusions	Feicheng Xangzhuang Shaft No.2	1962	Bank No.302, with the overlying alluvion 54 m in thick and coal and rock pillars 11.6 m in height, got minor fault, along which water and sand intruded for hundreds of cubic meters. A pit was emerged from the ground.	Bump range extended to the alluviums.	Intrusions also happened in Lieshan, Tangjiazhuang, Qishan, Shenchun, Caili, Xientai, Jingjing and Kongji mines, causing losses.
Examples of yellow mud intrusions	Doulishan Xianghuatai Shaft	1977	Yellow mud intrusions occured at the face end of the eastern main opening (-100 m), which stopped up the openings for over 80 m and covered the rock loaders.	Sudden gush of gravity	
	Huping Shaft	1977	Mud intrusions occured for 200 m^3 in the Uphill No.122, by which the fan pipes, water pipes and circuits were destroyed in the working place for 300 m.	" "	From Feb. 8 to Apr. 6, 1972, when tunnelling in the main return-air courses at the bottom of the air duct of the Maokou limestone, intrusions of mud and rock into the openings occured successively in 5 places, with the amount of 3,000 m^3.
	Shaft No.2 of Enkou Mine	1977	Mud intrusions occured in the southern main return-air courses (+50 m), which stopped up the openings for over 50 m, causing hold up of work for clearance for 10 days.	" "	
	Meitanba Zhushantang Shaft	Sep. 1980	Mud intrusions occured in the eastern main level opening (-90 m), with the amount of 500 m^3, by which a lump rock of 1 ton or so was pushed out over 10 m.	" "	Since 1974, mud intrusions happened in succession for more than 20 times. The Zhushantang Shaft, with developed faults, was intruded by mud for 12 times within 14 years, one of which, in Sep., 1980, caused loss of lives.
	Leping (in Jiangxi Province) Mingshannan Inclined Shaft	July, 1970	The elevation of -49.5 m led to water intrusions, then, a large amount of red mug sludge, slit and fragments of limestone, causing a sinking ground. The shaft was covered when the amount of water increased to 480 m^3/h.	Rock moved when the roof was blasting down for extracting, which linked up with the Changxing limestone water in the upper part.	The shaft has not been recovered till now.
	Lumaojiang Shaft No.3	Nov. 1981	The intrusions of Shidengzi limestone reached to over 3,000 m^3, which stopped up the openings for more than 1,000 m.	Sudden gush of gravity	Loss of lives caused by the lack of preventive measure and the unclear safe route, leading to stop of production.

Coal measures cropped up in many mining areas which are draped with thick and loose strata or near the riverbeds. Although preservation of coal pillars was usually adopted, accidents of mud solid intrusions into mining pits were unavoidable, which were different from the intrusions of lumps of coal and rock that mentioned above. This kind of accident is mainly due to the sand-rock-mud flow, that is mixed with underground and surface water. It is a hidden danger that should not be ignored by the engineers of hydrogeology and engineering geology. The author, in Xinhe Mine of Xuzhou in 1965, observed Sean B of the dip of 87^{o} at the Bank No.205, which was intruded by the sand-rock-mud flow when mining. Though pillars (31 m in height) were kept to prevent the bumps of the loose overlying layers with the thickness of 49 m, intrusions occured for the exceeding mined pillars in local places. Openings of 1,200 m were filled by the flow within 3.5 hours, causing a funnel-shaped chasm, which did great damage to production. A mine in Hebei Province, on Nov. 19, 1973, was intruded by sand-rock-mud flow for the exceeding mined pillars of several thousand tons, of which solids intruded into shaft with the speed of 11 m/min. and caused damage to production. In some mines, the intrusions were due to the mining with insufficient pillars, not even pillars, such as Yangzhuang and Tangshan mines (Table 1). Besides, in South China, some shafts were intruded by the loose materials through karst-cave cracks.

In recent years, it was reported that the intrusions of yellow mud in karst-cave into pits occured in succession in some mines of karst coalfields of Post-Permian. For instance, many times of mud intrusions occured in Huping Shaft in 1972, one of which with the amount of 2,000 m^3 in the Uphill No.122, causing losses of fan pipes, water pipes and circuits in the working place. The clearance of mud at the time of tunneling (27.5 m^3/m) was done in the main level return-air courses (+70 m) because of mud intrusions; intrusions occured three times in a karst-cave, that the opening had to be detoured. A crack of 0.7 m occured at the tunneling end of the eastern main level opening (-90 m) in Zhushantang Shaft in Meitanba, which is filled by mud; after the miners withdrew from the place when hearing the abnormal sound, the mud intruded into the opening for 19.5 meters. Tunneling later was carried on in another direction, and muddy water was found to leak out from the borehole of the tunneling end. Uphill that conveyed materials was dug from the Starting Point No.3. Sound of air leak was heard at the time of blasting on Sep. 23th, 1980, mud intrusions occured in the dug Starting Point No.2 with the amount of 500 m^3, by which a lump rock of 1 ton or so was pushed out over ten meters, causing great losses to personnel safety and production. Moreover, mud intrusions, some of which were intercalated with crushed rock and grit gravel, occured in the iron deposits in Enkou, Lumaojiang and Xiangzhong.

All the examples above mentioned show clearly that solid intrusions into mining pits is very damaging, it is necessary to study its mechanism and prevention methods.

Effective Factors of Solid Intrusions into Mining Pits

From the sourses of the three kinds of solid intrusions, yellow mud came from the karst-cave system of limestone, with evenly and fine graded particles, great viscosity, brownish-red to brownish-yellow in color, of which some was as thick as mud ball, some as thin as gruel. Sand-rock-mud flow came mostly from the loose deposits of the terrene and deposits of the riverbed, both of which were mainly stored over the mining engineering, causing intrusions by gravity. The flow was mainly in the form of mud flow or mud-rock flow for the mixing of underground and surface water. Its velocity depended on the pressure head and consistency. The coal and rock came from the original rock --- the mined layers, causing intrusions by the stress and the additive worked-out stress.

Mud intrusions occured many times in Xiangzhong Coalfield for the karst-cave cracks, which were developed by the Maokou limestone of the underlying Longtan coal layers, made up the storage places for yellow mud, with the addition of plentiful precipitation, excessive surface water systems and abundant underground water, and the situation of karst water pressure area (Table 2). Mud intrusions in the Zhushantang Shaft of the Meitanba Mine and the Huangguang Shaft of the Doulishan Mine showed that complex structure provided good conditions for mud storage and mud intrusions.

Examples of mud intrusions in China often occured in the syncline, anticline and fault zones, or bed thinning zones,where were the stress-concentrated regions. Coal seams of Permian in the Tianchi Mine changed greatly, and was dry, with the roof of heavy Changxing limestone. Altogether 28 SRS happened in the mine, 20 of which occured in the stress-concentrated sections of anticline and syncline. 114 SRS occured mostly (nearly 80%) in complex structure regions in Jingxi Mine, 66 of which happened in syncline zones, 20 at the axis of the structural basin. Different views about these are held by the researchers at home and abroad. The American specialists consider that the fault structure in the Utah Coalfield is the direct medium leading the intrusions by the sudden release of level stress. Some Chinese geomechanics researchers hold that the stress-concentrated regions are generally in the intersections of macro faults, the diversion of faults, the across faults of the arch structure and the convergence of faults. Stress would be increased when openings were tunnelled in rock mass; moreover, stress would be more concentrated if the openings were in the stress-concentrated zones. Rrsearchers in the Federal Republic of Germany think that SRS often occured in the simple structure regions, of which the storage and release of stress were in close relationship with the agersis of rock crack. For instance, researches for the Ruhr mining area showed that SRS born no relation to the faults, the metamorphic grade of rock and the stratum ages.

A large amount of SRS data show that SRS is in close relationship with the physical and mechanical properties of rock. When the hardness coeffcient is more than 8 (generally 7 - 9) and the compressive strength more than 800 kg/cm^2 (generally 1,650 - 1,896 kg/cm^2), the rock is elastic and easy for the storage of stress, by which SRS occurs with ease. The rock, which is high in temperature and watery, is unfavorable for the storage of stress, that SRS is not easy to happened, not to mention rock intrusions.

Moreover, depth is also the important condition for the storage of stress and occurence of SRS. In China, 4 SRS happened at the depth of 400 m in the Tianchi Mine of Sicuan Province, while 24 at the depth of 400 - 700 m. The Seam No.5 in Tangshan mining area is 1 - 2 m thick, with the roof of sandstone, while SRS occured in the Bank No.2151 at the depth of 700 m, causing great losses to production. In the Federal Republic of Germany, 283 SRS that happened over the years in the Ruhr mining area, occured at the depth of 590 - 1,100 m, 75% of which at the depth of 850 - 1,000 m, while the largest rock intrusions had the amount of 2,000 m^3. In American, SRS occured but with few times, concerning with its shallow mining. In Poland, from 1971 to 1975, SRS happened 2 times at the depth of 301 - 400 m, 6 times at 401 - 500 m, 30 times at 501 - 600 m, 33 times at 601 - 700 m. Obviously, SRS increased with the mining depth. So

Table 2. Relationship between Stored Mud, Mud Intrusions and Karst Water Discharge

Mine	Shaft	Names of openings in the Maokou limestone	Positions of karst water discharge	Damage	Note
Doulishan	Xiangshuatai	Face end of the eastern main opening (-100 m)	Pressure discharge	The openings were stopped up for over 80 m, rock loaders were covered.	Cave mud deposit did not occur, for the west limb of the shaft is near Donglf, with good conditions for discharge.
		Cross-cut No.2 of the Working Place No. 232	" "	Two times of mud intrusions occured, each of which stopped up openings for 30 m.	
	Maping	The southern main opening (-100 m)	" "	Two times of mud intrusions occured, that stopped up the openings for 200 m.	The shaft was situated in the pressure didcharge area between the Ganxichong recharge area and the spring discharge zone, so mud intrusions occured in succession.
		Uphill No.122	" "	Mud intrusions of over 200 m^3 occured in Mar., 1977.	
		Uphill No.122	" "	Mud intrusions of 200 m^3 occured in Mar., 1977, causing damage to water pipes, fan pipes and circuits.	
		Main return-air courses (+70 m)	" "	Mud was cleared when tunnelling (27.5 m/m^3).	
Bakou		Southern main return-air courses (+50 m)	" "	Stopped up openings for more than 50 m.	

the Polish researchers, from the conditions and examples, considered that the critical depth of SRS was 400 m.

Prevention of Solid Intrusions into Mining Pits

It is very important to study the effective methods for prevention, for the great losses of the shafts caused by the intrusions of loose layers, karst-cave mud and coal and rock.

Reservation of coal pillars is mainly used in China and other countries in order to prevent the intrusions of loose layers. At present, research work should be engaged on the possibilities and intrusion conditions of the formation of sand-rock-mud flow in some new mining areas. Although data were provided in the exploration stage, study of prevention of solid intrusions should be made prior to mining, and effective methods for prevention should be adopted.

For the prevention of mud intrusions in karst regions, investigation should be made first. In addition, drilling and geophysical prospecting should be done in the major areas to ascertain the development and distribution law of karst, discharge of underground water and conditions of sources of karst-cave mud. Assessment and analyses on the possibilities and state of mud intrusions should be made from the space and form of the mud-stored karst-cave, being as the major reference data for the forecast of mud intrusions. Clearance is a complete and effective method for the forward mud intrusions with the form of fluid flow in small amounts. The caves can be sealed up by laying after clearance. In Xiangzhong, the cross roof was laid with some cushion materials, such as grass, branches and gangue. Method of sealing up first, detouring later can be used under suitable conditions, for the clearance method takes times and the ground may be sunk, causing damage to the buildings above. Mud intrusions into mineral deposits in karst areas are often in complex situation. Take the Huping Mine in Xiangzhong for example, straight-pipe mud-stored karst cave system occured in the main return-air courses (+70 m), the main opening (+14 m) and the southern main opening (-100 m), causing mud intrusions after ventilation of the southern main opening (-100 m) traversed for 200 m, mud intrusions from the drained karst-cave began to occur again, that stopped up the main opening for 200 m, causing stopping of production. Therefore, in addition to the clear requirement of the exploration specifications, and the combination of drilling and geophysical prospecting with pretion, great attention should be taken to that when control un watering is made in this type of deposit, the high-lying energy hanging of the mud and sand fillers in karst-cave shall be made as less as possible.

Forecast of SRS in mines and the adoption of explosion-proof mining facilities are the very problem concerned by the mining engineers both at home and abroad. At present, comprehensive forecast methods are used in the USSR, while microseismic recorders are used in the US. Stress control is a fundamental method which avoids stress concentration, being used in China and other countries. It consists of equitable distribution for mining, blasting down the roof timely in averting extensive hanging and explosion relief. Geological techniques are also used, such as water injection and pressure relief of hole drilling.

Water Injection Method: Water is injected into the stress-stored coal seams and their roof, by which the strata are wet and plastic, then relieved, causing the removal of the tendency of coal and rock intrusions. The distribution, pressure and injection quantity of the injection holes should be enough for the plastication and subduction of the strata. The structure of the injected coal seams should be complete, and has the water permeability, with the porosity less than 4%. The roof rock should have the plastic characteristic when meeting with water. This method has been widely used in the USSR, Poland, the Federal Republic of Germany and other countries. Also, the method has been used in Datong, Jingxi, Zhaozhuang in China, and actual effects have been got. Take the Xinzhuang mining area of the Mentougou Mine, which coal and rock intrusions occured, for example, 8 SRS happened with the Richter scale of over 2.3 in the south part of the slope of the Slot No.8 after water injection; while 33 SRS occured with the Richter scale of over 2.3 in the north part of the slope, which was not injected. In the Tianchi Mine of Sichuan Province, it was also proved that rock was plastic and the hardness and elasticity of rock were decreased after water injection.

Method for Pressure Relief of Hole Drilling: The elastic energy of coal seams was relieved by drilling holes, which was used by the Federal Republic of Germany, following the USSR, Japan and other countries. Drill holes of 95 - 105 mm in diameter were run in the great stress-stored coal seams and strata, by the powerful remote control drillers under different conditions. The aperture, depth and spacing are determined according to the concrete conditions. In the Workuta mining area of the USSR, drilling was run at the spacing of 1.0 - 1.5 m by the drillers with the diameter of 300 mm and results were achieved, which was considered as a reliable method for elastic energy relief.

Conclusions

Mud intrusions, rock burst and sand-rock-mud flow are the objective phenomena in mining, which do harm to production, sometimes, are as harmful as the water intrusion of the karst deposit. It is natural to bring these problems into the research category of engineering geology and hydrogeology in mining pits. For the researches of SRS (mine impact), in the USSR, besides the mining departments, some units have made researches on these problems, for example, the Russian Institute of Geomechanics and Mining, Geomechanics Institute of Academy of Sciences of Kirghizia, Institute of Geology and Exploration, and the Vostochny Institute of Geology and Exploration, etc. The Geological Survey of America is one of the units that make researches on this project. In the geological circles in Cnina, few people got involved in these problems, particularly the engineering geology and hydrogeology researchers. It is very important to study on them, judged by the needs of practice and discipline. From the point of view of engineering geology, examinations should be made on the distribution of the contemporary stress field, the lithology and physical characters, stored energy relief conditions and their mechanism, effect of water for rock intrusions under different conditions in different places, relations between fault structure and rock intrusions, in order to determine the appraisal of the standards and parameters of SRS. Further researches should be made more scientifically and economically on the given prevention methods, for example, the usefulness of the decrease of stress concentration of the water injection method and the method for pressure relief of hole drilling. Researches should be also enhanced on the forecast and exploration, the control measures of the mud intrusions and the forecast of sand-rock-mud flow of the mud-stored karst-cave systems in South China.