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The review of geohazards in Xiaolongtan Lignite Deposite

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Abstract. This paper reviews the various aspects of the Xiaolongtan Lignite deposit mine and summarizes the geological disasters of Buzaoba pit, Xiaolongtan pit and Xindenger dump, including landslides, floods, bench erosion, the physical-mechanical changes caused by spring water and lignite spontaneous combustion.

1. Introduction
The studied locality (GPS: E 103°11′52″, N23°48′45″) is the Xiaolongtan Lignite Deposit in Xiaolongtan Town which besides Gejiu City in Yunnan Province, south-west of China, where two enormous open-pits (No1: Buzaoba open-pit and No2: Xiaolongtan open-pit) could be seen in satellite images (Figure 1 and Figure 2). The Lignite deposit belongs to the largest lignite mines in China. It annually produces 14.9 million tons of Lignite, while 13 million tons from Buzaoba open-pit and 1.9 million from Xiaolongtan open-pit.

![Figure 1. The location of Xiaolongtan lignite deposit mine](image-url)
The lignite comes under Xiaolongtan Mining Bureau, which is a state-owned enterprise. The deposit plays a crucial role in the fossil fuel industry in Yunnan Province. The deposit began to produce from September 1954, after decades, the surface mining and 5 stages extension, two great open-pits appeared. The biggest open-pits in China: Buzaoba open-pit and Xiaolongtan open-pit. Buzaoba open-pit was determined of surface area 5.2 km² and depth 226m, which is bigger and deeper than Xiaolongtan open-pit’s 2.2845 km² and 160m. The 10m bench height makes the bench slope angle approximately 60° in both pits.

The designed exploitation capacity of studied open-pits is $3420 \times 10^6$ m³ in Buzaoba pit and $930 \times 10^6$ m³ in Xiaolongtan pit. Until now, the total extracted capacity of Buzaoba pit is reaching $1180 \times 10^6$ m³ and Xiaolongtan pit is $370 \times 10^6$ m³, illustrated the reserved capacity of Buzaoba open-pit is $2240 \times 10^6$ m³ and Xiaolongtan open-pit is $560 \times 10^6$ m³.

The total lignite capacity of Buzaoba open-pit is $730 \times 10^6$ m³ and Xiaolongtan open-pit is $180 \times 10^6$ m³. Until now, the extracted lignite capacity in Buzaoba open-pit is $280 \times 10^6$ m³ and in Xiaolongtan open-pit is $107 \times 10^6$ m³, thus the reserved capacity of lignite of Buzaoba open-pit is $450 \times 10^6$ m³ and Xiaolongtan open-pit is $73 \times 10^6$ m³ (see Figure 3).
The waste-rock excavated from Buzaoba open-pit is externally dumped in Longqiao Waste-rock Dump and Xindenger Waste-rock Dump, the former one is located in 1km away from the west border of Buzaoba open-pit and the latter one is located in 3km away from south-west border of the pit.

What’s more, the designed capacity of Longqiao Dump is $631 \times 10^6 \text{ m}^3$, elevation designed from 1225m to 1525m, now the height is reaching 1465m. While, the designed capacity of Xindenger Dump is $176.02 \times 10^6 \text{ m}^3$, elevation designed from 1225m to 1530m, now the height is reaching 1410m. The waste-rock excavated from Xiaolongtan open-pit is externally dumped in Beipingba Waste-rock Dump, which is located in 1.4km from the north border of Xiaolongtan open-pit. The designed capacity of Beipingba Dump is $53.09 \times 10^6 \text{ m}^3$, the designed elevation is from 1140m to 1290m, now the height is reaching 1275m.

The paper deals with a series of geohazards that occurred in research locality Xiaolongtan Lignite Deposit due to the complex geological condition, climate condition, technological method and so on. To study the relationship between the geohazards and engineering geological condition would attribute to discovering potential hazards and giving pieces of advice to further mining.

2. Literature review

In order to collect essential information about research open-pits Buzaoba open-pit and Xiaolongtan open-pit, the studies of Xiaolongtan Lignite Deposit are all carefully reviewed, for instance: Li et al. (2015) did a research of magnetostratigraphic on Xiaolongtan Formation to constrain the initiation time of the southern segment of Xianshuihe-Xiaojiang fault. The rock magnetic experiment results indicated the age of Xiaolongtan Formation ranges from ~ 10 Ma to 12.7 Ma. [1] While, Shui et al. (2009) was interested in the liquefaction properties of Xiaolongtan Lignite under different atmospheres (H$_2$, THN, N$_2$ and CO), the results indicated that using water as solvent under CO atmosphere was the best solution. [2] Also, Donglai et al. (2010) analysed the different production conditions under different mining technique, the results showed a semi-continuous stripping and mining technique – hammer-roller crusher was the best choice. [3] Moreover, Qing et al. (2007) focused on the stability of the west slope of Buzaoba open-pit, Xiaolongtan lignite deposit, the numerical simulation was used and result in solutions for slopes designing and repairing. [4] What is more, Huang et al. (2011) studies the middle-lower part of Xiaolongtan Formation, and seismites were initially found by authors, the discovery could provide data to further research of palaeoseismic activity of the research filed. [5] Further Han et al. (2015) analysed the influence of vibration load on rock mass structure and slope stability of the west slope of Xiaolongtan deposit, the anti-sliding force and sliding force were obtained, the results showed that the difference of blasting time and slope stability negatively related to each other. [6] In addition, Guo et al. (2011) was interested in the energy and exergy analysis for 300 MW thermal system of Xiaolongtan power plant, the results showed the energy loss mainly occurred in the condenser. [7] Also, Li et al. (2010) analysed SEM and XRD of the residual clinker of Xiaolongtan lignite in a different method, try to explore the compositions, surface morphologies and crystals under different conditions. The results indicated that XLT clinker formation during fluidized-bed gasification is mainly caused by anorthite, gehlenite and hedenbergite under 950°C. [8]

Due to the location of Xiaolongtan Lignite Deposit is special from the tectonic geological point of view, thus, the studies of petrology, magnetostratigraphy and stratigraphy are highly developed. In
addition, the research of maximization utilization of the lignite is highly developed too. As for engineering geology, the researches of the influence of vibration load on rock mass structure, the slope stability of the west slope of Buzaoba open-pit and the liquefaction properties of Xiaolongtan Lignite under different atmospheres (H₂, THN, N₂ and CO) are limited.

3. The geohazards in Xiaolongtan lignite deposit mine

3.1 Landslides

The multiple rotation genetic landslide in Xiaolongtan Lignite Deposit was widely investigated and analysed by Chinese researchers. [8-13] The most dangerous documentary landslide occurred in the west slope of Buzaoba pit, which was formed by mixed materials (Q₄ml), diluvial (Q₄dl+pl), marl (N₁₂X⁴), main lignite seam (N₁₂X³) and clay (N₁₂X¹-²). The physical and mechanical properties of the formation are shown in Table 1. [9]

| Strata                        | Density t/m³ | Cohesion kPa | Friction angle φ° | Modulus of Elasticity Gpa | Poisson Ratio |
|-------------------------------|--------------|--------------|-------------------|---------------------------|---------------|
| Mixed materials Q⁴            | 18.62        | 13.9         | 18.26             | 0.014                     | 0.42          |
| Main lignite seam (N₁₂X³)     | 13           | 28           | 17.5              | 0.168                     | 0.33          |
| Clay (N₁₂X¹-²)                | 20.5         | 31           | 11.83             | 0.035                     | 0.39          |
| Marl (N₁₂X⁴)                 | 21.4         | 210.4        | 28.91             | 6.597                     | 0.24          |

The data is monitoring by GPS, and the main slide direction was considered as 105°-110°, the deformation information can be seen in Figure 4 and Figure 5.

Figure 4. The duration curve of horizontal displacement from 3 different locations in Buzaoba pit [9]

Figure 5. The duration curve of vertical displacement from 2 different locations in western slope of Buzaoba pit [9]
Combined with the duration curve of the horizontal and vertical displacement from the west slope, the most dangerous displacement from May to June 2010 can be seen.

What more, a documentary landslide also has been found in the north side of Buzaoba pit, which was formed by the mixed materials ($Q_4^{m}$), the main lignite seam ($N_{1-2}x^3$), clay ($N_{1-2}x^{1-2}$) and limestone ($T_{2g}$), which contained many weak planes. The landslide occurred on November 11, 2011, the displacement curve in the northern slope of Buzaoba pit is shown in Figure 6. The whole duration of the landslide was 5 hours, the total area covered $1.9 \times 10^4$ m$^2$, the total volume reached $3.52 \times 10^6$ m$^3$.

Figure 6. The displacement curve from 2 different locations in the northern slope of Buzaoba pit [12]

Also, there is a potential landslide in the north slope of Xiaolongtan pit, the duration curve of horizontal displacement from the north and southeast slope could be seen in Figure 7. The [14] potential sliding surface was considered in clay ($N_{1-2}x^{1-2}$) and main lignite seam ($N_{1-2}x^3$), which was distributed in a zigzag pattern. Through the analysis of monitoring data, the north slope of Xiaolongtan pit was considered in the creep deformation period.

Figure 7. The duration curve of horizontal displacement from the north and southeast slope of Xiaolongtan pit [12]

3.2 Floods and bench erosion
Two open pits are separated by Nanpan River. The hydrological condition of Xiaolongtan Lignite deposit could be seen in Figure 8 in details. Because the two pits are at low water levels and below the erosion base level, ground water and precipitation can cause pit water discharge and bench erosion. The bench erosion can cause the slope to collapse (Figure 9).
3.3 Changes in physical mechanic properties caused by springs

The Xindenger dump located in the dissolution featured middle-mountain. The location also refers to the basin arc discharge zone of the Southwest Basin, which we can see from Figure 3 and Figure 8. Many springs were found and recorded in the discharge zone. The most dangerous one is a seasonal spring, which is recharged by runoff and influenced by precipitation. On August 31, 2013,
groundwater oozes from the ground, creating a severe regional reservoir in Xindenger dump (see Figure 10). The process changes the physical mechanic properties of the mixed materials, leading to the instability of the slopes in Xindenger dump.

**Figure 10.** The flowslide in Xindenger dump

3.4 Spontaneous combustion of lignite

The characteristics of spontaneous combustion in open pit lignite seams are that the fire source comes from the inside of the lignite seam, and most of the spontaneous combustion occurs in the range of 0.5 m to 3m from the surface. Oxygen oxidation of low temperature and oxygen may occur in the loose lignite seams, and the air may be self-supplied by the thermal circulation. It has the characteristics of the hidden fire source, and the loose lignite layer is easy to store heat and is not easy to dissipate heat. Once discovered, it has been burned down in large areas. As can be seen from Figure 11, spontaneous combustion can be seen in both pits, especially during the summer months.

**Figure 11.** The spontaneous combustion of lignite

4. Conclusions

The geological disasters of Xiaolongtan Lignite Deposit Mine (Buzaoba pit, Xiaolongtan pit and Xindenger dump), including landslides, floods, bench erosion, the physical mechanics changes caused by spring water and lignite spontaneous combustion cause threats to the safety of mining activities. This paper describe the disasters in details to provide support for further research and mining.
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