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Redesigning the geometry of the Makala Coal Mine to improve safety and productivity

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ABSTRACT
Makala is a room-and-pillar coal mine situated in the Katanga Province (DR Congo), close to the city of Kalemie (eastern part of the country). It exploits the so-named Lukuga Coal Basin, which is composed of four coal seams numbered 1 to 4. The economically mineable are 1 (about 2m thickness) and 2 (1 to 1.5m thickness). This coal basin shows some similarities with south-African deposits (Cahen 1961, in Carte Géologique du Zaïre). From the West the deposit plunges towards the East with an average dip of 8°. Mining operations using room-and-pillar method started in 1914 on the northwestern part of the deposit, following the outcrops of coal seams. Currently only seam 1 is being mined out and the workings are being developed southwards to avoid the higher overburden towards the East. Despite the increasing thickness of the overburden, the geometry of the method does not vary, and consists of rooms 4m wide and pillars of 8x6m, leading to a recovery of about 60%. The main gallery lays from North to South for more than a kilometer. Panels situated on the western part of the main gallery are composed with stable pillars, while on the eastern part one can observe some typical problems like pillar fracturing, ground heave and roof falls. In this last case we noticed that the roof of seam 1 is of poor mechanical quality.
In order to understand the geomechanical problems, we first built a 3D geometrical model, updating the mine layout and incorporating both geological and topographical data. This modelling has been achieved using the GEOVIA-GEMS software. The approach helped in assessing as accurately as possible the overburden to be taken into account when calculating the weight to be supported by pillars. From the defined geometry, we used the modified tributary area method (Brady and Brown 1999) to redesign the pillars accordingly. 2D numerical modelling has been used as well to assess the stability of the roof and dimension timber support used in the mine.
KEYWORDS: room-and-pillar mining, mine design, tributary area

1. INTRODUCTION

Makala is a room-and-pillar coal mine situated in the Katanga Province (DRC), close to the city of Kalemie. This coal basin was discovered in 1911 and mining started in 1914 on the northwestern part of the deposit, following the outcrops of coal seams. Currently, only seam 1 is being mined out and the workings are being developed southwards to avoid the higher overburden towards the East.

Despite the increasing thickness of the overburden, the geometry of the method does not vary: it consists in 4m wide rooms and 8x6m pillars, leading to a recovery of about 60%. Whereas panels situated on the western part of the main gallery are composed of stable pillars, typical problems are encountered on the eastern part: pillar fracturing, ground heave, and roof falls. In addition, the roof of seam 1 is of poor mechanical quality.

This study intends to understand the geomechanical problems and propose a new design for the pillars accounting for the increasing depth of the orebody. Meanwhile, a 2D numerical simulation is conducted to assess the stability of the roof and dimension of the timber support used in the mine.

2. GEOLOGICAL CONTEXT

The Katanga coalfields (Luena, Lukuga…) are similar to southern African ones (Cahen 1961, in Carte Géologique du Zaïre). The coal deposits were formed during Permian and Carboniferous ages and resulted in lenticular coal seams with a high ash content and highly volatile matter content. Different explorative works have been undergone in the area (1930, 1953 to 1954, early 2000…) but the most complete geological description is the one from Jamotte (1931) which is based on 15 core drillings (total length 1800 m), trenches and outcrops observation. Table 1 gives a typical succession of geological formations as observed in drillholes S1 and S4.

The Makala mine is located in the Lukuga Basin (Figure 1). The orebody has been affected by faults during the formation of the Tanganyka graben.

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Table 1: Geological formations in the seam 1 neighborhood.

Geological formation	Thickness S1 (m)	Thickness S4 (m)
H3: feldspathic sandstone	4	3.72
Seam 2 with a footwall of psammitic sandstone	0.9	1.15
H2: zone Psammites, sandy sometimes	1.8	3.33
H1: coarse sandstone, feldspathic, conglomerate sometimes	4.13	7.3
Seam 1 with a footwall in grey argillaceous shale	2.4	1.81
Psammites and black shales with coal	2.85	2.29

The mined area is situated to the East of the Hôpital Fault and to the South of the Lukuga River, where the thickest outcrops of seam 1 have been found in the Nikuha Valley. The orebody strikes in a N-S or NE-SW direction, with an 8° dip to the E-SE. Figure 2 gives a typical cross-section of the orebody showing the increase of the overburden towards the East.

According to the available data (Woitrin and Delvaux), if we consider the panel defined by the 200m barrier pillar separating the mined area from the Lukuga River, the Hôpital Fault to the West, the Kaniki Fault to the South-West and the Kandeke Fault to the East, the coal in seam 1 may represent 7 642 250 mineable tons. This assessment is based on a 2 m thickness of the seam 1 and a recovery of about 60% by the room-and-pillar mining. Mining seams 2 and 3 could also represent another 7 642 250 tons. For the whole basin, Cailteux (2006) assesses the coal reserves to more than 75 million tons, meaning that this area has interesting potential.

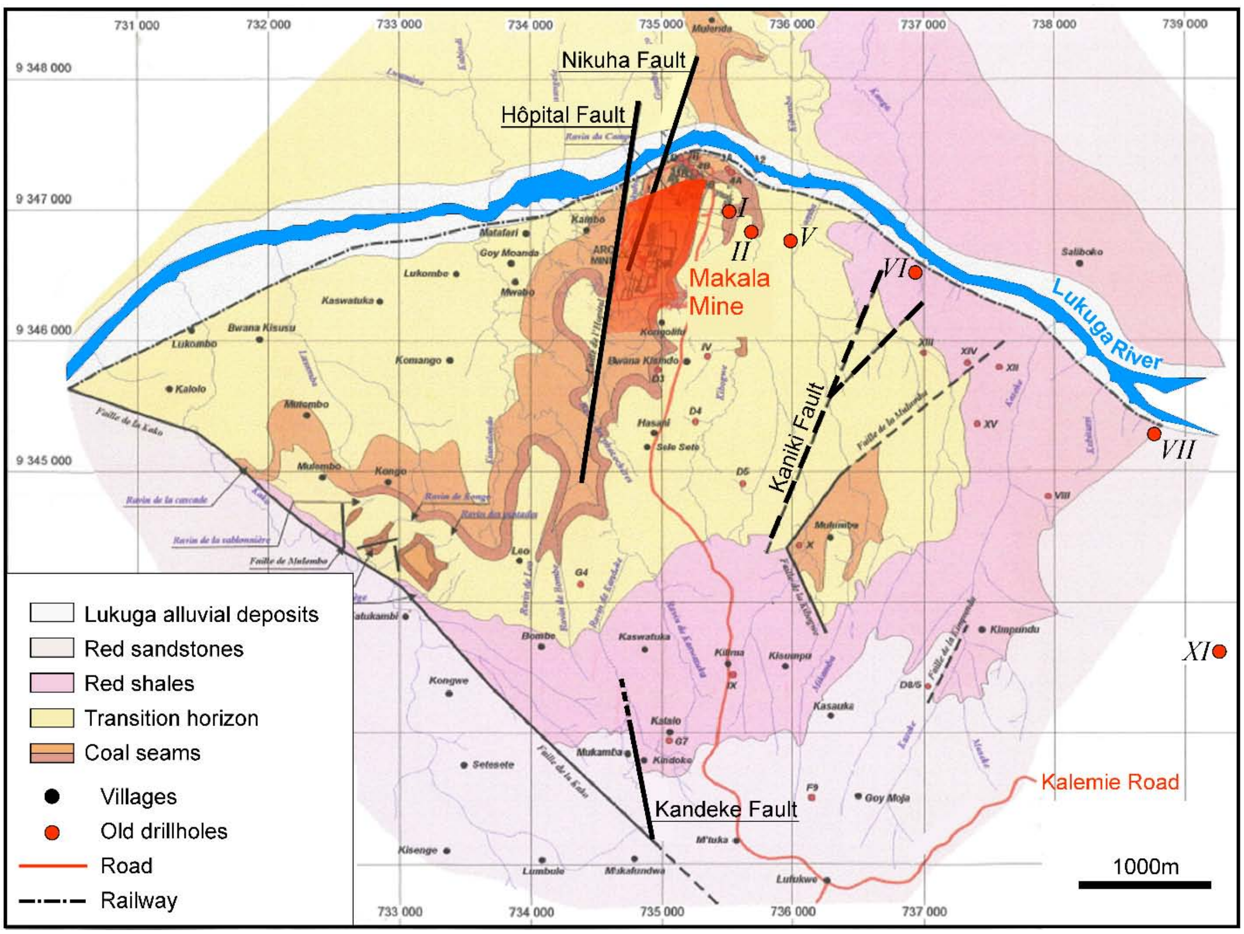

Figure 1: Geological map of the Lukuga coalfield (modified from EGMF, after Jamotte 1931.

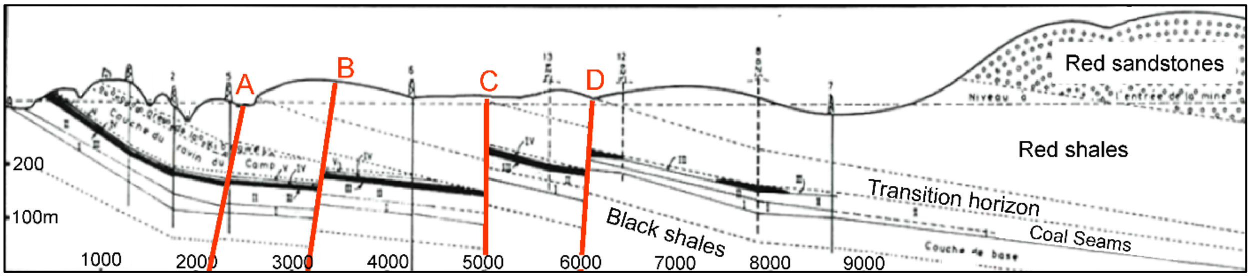

Figure 2: Typical cross-section of the orebody through drillholes I, II, V, VI, VII, XI (Jamotte 1931). A, Mikamba Fault. B, Kaniki Fault. C, Fault. D, Mulumba Fault.

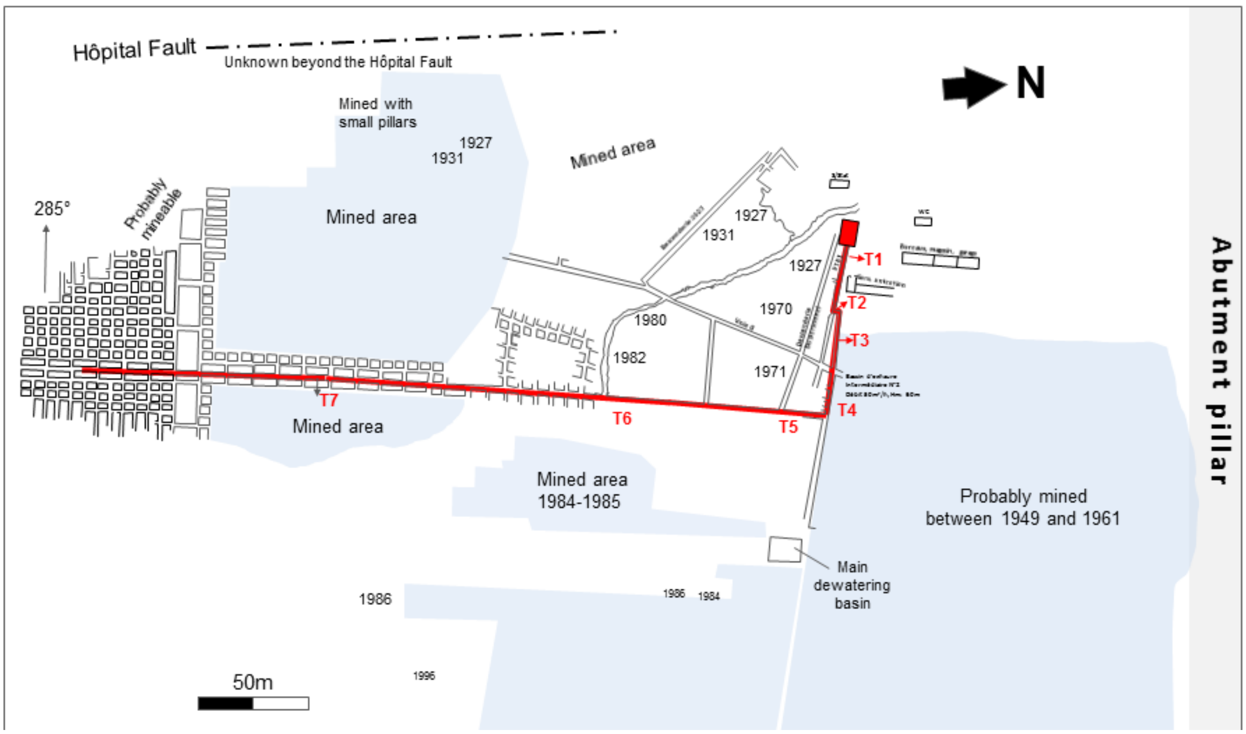

Figure 3: Mining map at Makala. In red, the main access from surface to the face.

3. MINING METHOD

Generally, only the seam 1 is mined even if in some areas the seam 2 has been also mined. Since 1914, the deposit has been mined by a room-and-pillar method with abandoned pillars. The mining operations started on the northern part and evolved towards the South. An abutment pillar with a width of 200 m has been left to the North to prevent water income from the Lukuga River (Figure 3). The main access is an inclined shaft that follows the seam and oriented according to the dipping. It crossed the Nikuha Fault and, due to the slip of this fault (8 m), the seam 2 has partly been mined in this area before the shaft joins again seam 1.

The inclined shaft is used for coal extraction to surface by means of a conveyor belt. It joins a directional gallery (or main gallery) with a N-S direction. This gallery is surrounded by a row of large pillars (20 x 6 m) for stability purposes. The longest part of the conveyor belt is installed in this directional gallery (more than a kilometer). A parallel way situated westerly with respect to the directional gallery is dedicated to workers.

When developing the layout, panels are created every 100 m along the directional gallery, leaving a row of barrier pillars (40 x 20 m) between panels. When the main gallery is mined out for a panel, 4 m-wide raises and declines are mined on dip before cross-cutting the long pillars. Residual pillars in the panel have dimensions of about 8 x 6 m, giving a theoretical recovery of about 60%.

4. NEW DESIGN FOR THE MAKALA MINE

4.1 Rock mass qualification and mechanical properties of the rocks

The roof is made of an argillaceous material, with very bad mechanical behavior. In some places, mainly at crossings, roof falls are observed, leading to 50 cm to 1 m depth holes in the roof. A new pilot-gallery to be enlarged for a decline has been dug in 2011 to access the southern part of current mining operations. It is intended to improve ventilation. During the authors' visit on site, bad quality rocks were observed along its side walls.

A more detailed evaluation of the quality of the rock mass has been performed, using the Rock Mass Rating (RMR, Bieniawski 1973, 1984) and the Geological Strength Index (GSI, after Hoek and Brown 1998). Following the rock description along the new decline, the RMR is estimated between 20 and 40, corresponding to a poor quality rock mass. The GSI parameters are considered as "blocky/disturbed" and "poor" to "very poor", leading to GSI values of 25-30 for the coal seam 1 and the hanging wall.

In terms of mechanical properties, no experimental data were available for the coal, the hanging and the foot wall. The properties were assessed using bibliographic data (Vutukuri and Lama 1974, Hoek and Brown 1998) and by considering the low RMR value. The pillar strength is estimated to 5 MPa.

4.2 3D geometrical model of the overburden

A geological model needed to be built and coupled to the topography and the geometry of the workings in order to assess the thickness of the overburden. 13 drillholes described by Jamotte (1931) and a recent topography were used for this purpose. Mining data included an Autocad file delivered by EGMF for older workings, an up-to-date paper mine map (1/1000) and a recent file with survey data dealing with the access ways. We built the model using the GEOVIA-GEMS software.

The seam 1 is known to cross some faults but their position is not precisely documented. Therefore, the seam has been modelled as a monocline and its extension is limited to the surroundings of the mined area.

Based on available data, the geometry of the mining works has been modeled. Several vertical cross sections (W-E) have been plotted through the 3D geometrical model. Figure 4 shows the vertical cross-section 800N on which one can observe the dipping of seam 1 from left to right, the waving topography, and the description of a core drillhole.

In order to assess the overburden, Figure 5 gives the minimum (bottom) and maximum (top) elevations measured on each vertical section. The deepest works are found in the 800N cross-section but in this case an assumption was made on the topography due to missing data.

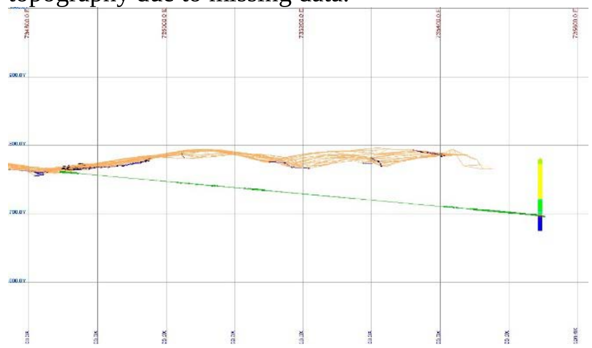

Figure 4: The 800N vertical cross-section showing the trace of seam 1, surface topography, and a description of a borehole.

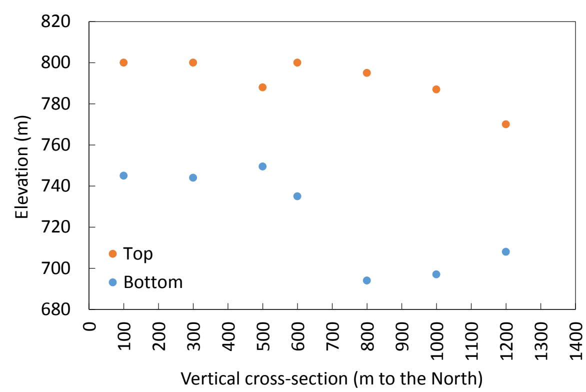

Figure 5: Measured elevations (top and bottom) in the vertical cross-sections from the 3D model.

4.3 New pillar design based on modified the tributary area method

The tributary area method (Brady and Brown 1999) is widely used in room-and-pillar mining design. The approach is accepted when the panel width is larger than the depth of the mined area. In the Makala mine case, this method can be considered as valid since the depth is about 50-60 m for 100 m panels.

The method for pillar design is rather simple but, due to the quality of the available data, it seems sufficient in comparison to more sophisticated methods like numerical simulations. The pillar strength is given as:

$$R_p = R_0 \; h^{\alpha} \; w^{\beta} \tag{1}$$

with R_p, the pillar strength, R_0, the rock strength, h, the pillar height, w, the pillar width. Parameters α and β

are assessed to -0.8 and 0.5 respectively, following values from the literature (Brady and Brown 1999). In the Makala mine, we obtain a pillar strength of 6.36 MPa.

The safety factor is defined as the ratio between the pillar strength to the mean vertical stress. Considering a mining depth of 60m and a specific gravity of 25 kN/m³, the vertical stress before mining is 1.5 MPa. The ratio between the surface of the area supported by the pillar and the section of the pillar is 2.5 and the stress on the top of pillars is 3.75 MPa. The safety factor equals 1.7.

The assessment of safety factors is based on empiricism. Salamon (Brady and Brown 1999) studied the performance of South-African coal mines pillars. From his analysis, one can see that intact pillars generally correspond to safety factors between 1.3 and 1.9. A reasonable approach for the Makala mine would be to suggest a safety factor of 1.6.

Due to the dipping of the seam, the pillar dimensions should change with the depth. In particular, the pillar size could be reduced in shallower panels resulting in an increased recovery. However, for deeper areas, the pillar size should increase and additional support may be necessary.

We computed the variation of the safety factor with the pillar width for various mining depths (Figure 6). The abacus indicates that for a depth of 90m, with the current assumptions,, a 1.6 safety factor cannot be reached even with 10 m wide pillars.

Based on the abacus, the pillar width is computed for a given depth in order to reach a safety factor of at least 1.6. The recovery ranges from 85% at a depth of 10 m to 52% for a depth of 70 m.

4.4 2D numerical simulation for assessing the stability of the roof and timber support

This approach is intended to better understand the mechanical behavior of the roof and adjacent pillar, and then assess the loading on support.

We assume a plane strain geometry (long continuous pillars) for a typical case occurring at 60m depth, and for two sets of mechanical properties corresponding to rock mass of either medium or poor quality. Computations were performed using the FLAC2D software.

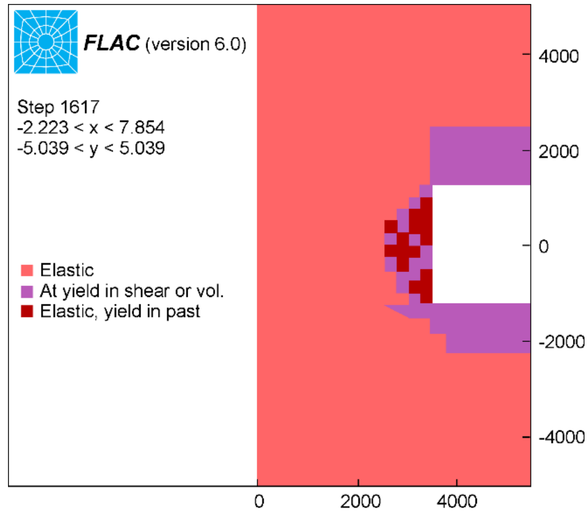

Figure 7: Yielding around a pillar in the case of a poor quality rock mass.

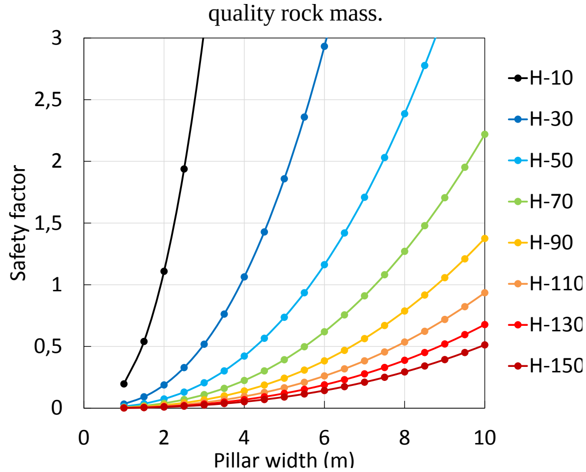

Figure 6: Safety factor as a function of pillar width for various mining depths.

Figure 7 corresponds to a case of poor quality rock mass when no support is installed. It shows a typical result gathered in terms of failure and plasticity and one can observe that both side walls, roof and ground are severely affected. In this case some support is to be envisaged, for instance by using roof bolts, or reduce the size of the rooms as suggested in section 4.3.

Depending on the technology and the distance at which the support is placed with respect to the current face, the extension of the damaged (or failed) zone can be limited. Different techniques can be envisaged: roof bolts, shotcrete, steel arches, etc. but the region of Makala is difficult to access for usual supplies. For roadways (4 m width), we then recommended mainly the use of either timber support or steel sets because the components can be accessed locally. For timber, we assessed the diameter of 15 to 17 cm, while for steel sets a H19 type was recommended. The normal spacing is 1 m from a set to the next but this can be reduced when geological conditions are very poor. A shotcrete can also be used for long duration roadways and galleries.

5. CONCLUSIONS

The Makala mine in DR Congo has been mined since the early 20th century using a room-and-pillar method. Despite an 8° dipping deposit, the dimensions of pillars and rooms do not change with the depth of operations, involving a low recovery at low depth and potential stability problems at higher depth. Geological studies have emphasized the remaining resources in the coalfield and a new design of the mine was necessary to improve recovery and ensure stability of future works.

During a visit undergone in 2011, the authors observed typical stability problems consisting in roof fall and ground heave for most of stopes situated on the eastern part of the main gallery. In order to understand the mechanical behavior of pillars, a 3D model was built including geological data gathered from drillholes, an updated general layout of the workings (mine map), and the surface topography. Analyzing the built model allowed an assessment of the variation of thickness of the overburden above the developed mine.

In a second step, the modified tributary area method is applied in order to assess the safety factor and also propose, for a given safety factor that we chose to be about 1.6, pillar dimensions depending on the mining depth.

Finally, a numerical simulation using the finite difference method is undergone in order to assess the stability of the working based on different sets of mechanical properties of the rock mass. To enforce safety, some recommendations have been made for support, especially for roadways and main galleries.

6. ACKNOWLEDGEMENT

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