Assessment of the Current Status of Mining Activities at the Synclinal Bottom in the Nam Mau Underground Coal Mine, Vietnam

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Abstract

Mining at synclinal bottoms represents a major technical challenge for underground coal mines in the Quang Ninh coal basin due to complex geological structures, high risks of water accumulation and gas concentration, and increased coal losses. This study presents a systematic assessment of mine opening schemes, field subdivision, mining methods, ventilation, transportation, and drainage applied at synclinal bottoms, using the Nam Mau underground coal mine as a representative case. The results indicate that the vertical misalignment of synclinal bottoms among coal seams is the primary constraint affecting mine development and production organization. The currently applied opening schemes, including the two-level opening system using crosscut roadways and raises, as well as the single-level opening by downward roadways, show distinct technical advantages and limitations. In particular, the two-level opening system provides superior ventilation and gravity-driven drainage conditions, thereby improving operational safety at synclinal bottoms, although it requires increased rock drivage and careful positioning to control coal losses. Field subdivision and longwall layout at synclinal bottoms are generally compatible with local structural characteristics; however, coal recovery rates and mechanization levels remain lower than international benchmarks. Comparative analysis with underground coal mines in China, Poland, Germany, and Australia highlights the need for optimized multi-level opening layouts, pre-drainage measures, and higher degrees of mechanization. The findings provide a scientific basis for optimizing synclinal bottom mining strategies in Vietnamese underground coal mines and support the transition toward safer and more efficient deep mining operations.

Keywords: *synclinal bottom mining, underground coal mine, mine opening system, longwall mining, ventilation and drainage*

1. Introduction

Underground coal mining in synclinal bottom areas represents one of the most technically challenging stages in the life cycle of coal mines, particularly under conditions of increasing mining depth and complex geological structures. In many coalfields worldwide, synclines are characterized by basin-shaped geometries, variable seam dip angles, unstable thickness, and complicated hydrogeological conditions [1]. These features often lead to water accumulation, methane concentration, difficult ventilation control, and increased coal losses, posing serious risks to both production efficiency and mine safety [2].

In recent decades, extensive research has been conducted internationally on mining methods and technical solutions for synclinal bottom extraction. In China, where underground coal mining frequently encounters deep synclinal structures, multi-level access systems combined with advanced geological modeling, mechanized longwall mining, and pre-drainage techniques have been widely applied to mitigate water and gas hazards and to improve recovery rates [3]. Studies have demonstrated that advance hydrogeological investigation and pre-drainage drilling significantly reduce water pressure and enhance mining safety in synclinal areas. In European coal mines, particularly in Poland and Germany, research has focused on optimizing panel geometry, roof control strategies, and longwall equipment adaptability under variable seam dip and structural deformation [4]. Numerical modeling and monitoring systems are commonly employed to support decision-making during synclinal bottom mining [5]. In Australia, highly mechanized and automated longwall systems, together with integrated mine planning and advanced ventilation-drainage designs, have enabled high recovery ratios and minimal coal losses even under complex structural conditions [6].

Compared with these international practices, research on synclinal bottom mining in Viet Nam remains relatively limited. Existing studies have mainly concentrated on specific technical aspects such as mine opening schemes, ventilation safety, drainage solutions, or water inrush prevention in underground coal mines [7, 8]. Several domestic studies have analyzed geological structures, hydrogeological conditions, and accident cases related to water inrush at synclinal bottoms in Quang Ninh coalfield, highlighting the high-risk nature of these areas [9]. However, most of these studies address individual problems or propose isolated technical measures, while comprehensive and systematic assessments of the entire mining process at synclinal bottoms covering mine opening, mining field subdivision, extraction technology, haulage, ventilation, and drainage are still scarce .

In Quang Ninh Province, the main underground coal mining region of Vietnam, many mines are currently entering deeper mining stages as coal reserves in the upper parts of seams are gradually depleted [10]. As a result, mining activities are increasingly shifting toward synclinal bottom areas, which are typically the lowest and most unfavorable zones of coal seams. Historical records indicate that serious incidents related to water inrush and gas accumulation have occurred during synclinal bottom mining, such as the water inrush accident at Tay Khe Sim mine in 2008. These events underline the urgent need for a thorough evaluation of current mining practices at synclinal bottoms to ensure safe, efficient, and sustainable coal production.

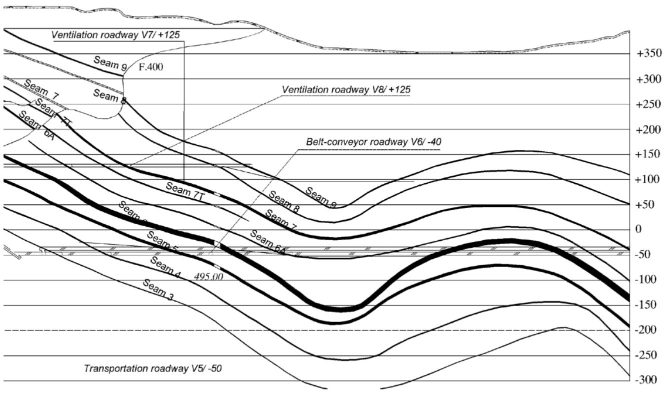

Fig. 1. Cross-section of the Nam Mau coal mine development scheme (or mine opening layout)
Rys. 1. Przekrój przez schemat rozwoju kopalni węgla Nam Mau (układ otwarcia kopalni)

Within this context, the Nam Mau underground coal mine is a representative case of synclinal bottom mining in Quang Ninh Province. The mine contains several synclinal structures, among which the H6 syncline is currently being accessed and prepared for mining across multiple coal seams. The applied mining solutions reflect common practices in Vietnamese underground coal mines, including two-level access systems, strike longwall mining, drilling-and-blasting extraction, and conventional ventilation and drainage arrangements [9]. However, these solutions also exhibit limitations related to mechanization level, drainage efficiency, and coal recovery.

Therefore, the objective of this study is to comprehensively assess the current status of mining activities at synclinal bottoms in the Nam Mau underground coal mine. The study focuses on evaluating mine opening schemes, mining field subdivision, extraction technology, haulage systems, ventilation organization, and drainage practices. By identifying the advantages, limitations, and underlying causes of existing solutions, this research aims to provide a scientific basis for proposing technical improvements and optimization strategies for synclinal bottom mining. The findings are expected to contribute not only to the improvement of mining practices at Nam Mau mine but also to the broader application of safer and more efficient synclinal bottom mining solutions in underground coal mines across Quang Ninh Province and Viet Nam as a whole.

2. Research Methodology

This study was conducted using an integrated approach that combines document analysis, field investigation, and comparative technical evaluation. First, mine design documents, mine development schemes, geological maps, and technical reports related to synclinal bottom mining at the Nam Mau coal mine were collected and analyzed. Based on these materials, the mine opening methods, mining field subdivision, and mining technologies that have been applied were systematized according to individual coal seams and different types of synclines.

In parallel, the authors assessed the current production conditions using key technical indicators, including recovery rate, coal loss, level of mechanization, ventilation efficiency, and drainage performance. A comparative method was employed to evaluate differences between opening systems (single-level and two-level opening) as well as among different coal seams within the same mine. The research results were synthesized to identify the advantages, limitations, and underlying causes associated with each applied solution.

The study employed the following main methods:

- Analysis of technical documents and mine layouts related to mine development, opening, and synclinal bottom mining.
- Comparative synthesis of mine opening methods and mining field subdivision at the Nam Mau coal mine.
- Evaluation of practical mining conditions based on the current status of mining technology, haulage, ventilation, and drainage systems applied at the mine.

The results were integrated and analyzed to clarify the strengths, weaknesses, and existing challenges in synclinal bottom mining.

3. Study area

The study area is the Nam Mau underground coal mine, a representative underground coal mine in Quang Ninh Province, located in the Uong Bi – Dong Trieu coal basin, northeastern Viet Nam. The Nam Mau coal mine is characterized by complex geological conditions, with multiple coal seams dipping from moderate to steep angles and being strongly influenced by folding and faulting. The mine comprises a relatively large underground mining area, with an industrial-scale production capacity and remaining recoverable reserves on the order of tens of millions of tonnes, typical of underground coal mines in the Quang Ninh coalfield. Within the mine boundary, several synclinal structures are developed. Among them, the H6 syncline is the principal structure currently being accessed and prepared for mining at the synclinal bottom of coal seams 6A, 7, 8, and 9. The synclinal bottoms of these seams are distributed approximately along the same stratigraphic column but occur at different elevations. This geological configuration creates significant technical challenges for mine opening, ventilation, and drainage, particularly in deep and water-bearing zones. The selection of the Nam Mau underground coal mine as the study area is highly representative of underground coal mines in Quang Ninh Province that are entering a stage of deep, structurally complex, and high-risk mining, especially with respect to synclinal bottom mining under conditions of water and gas hazards [9].

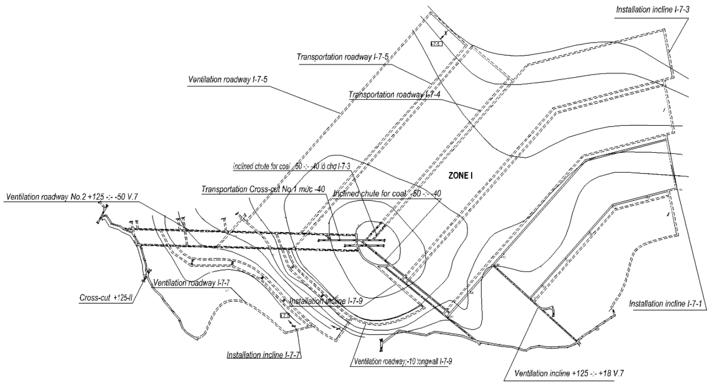

Fig. 2. Roadway layout scheme in the syncline area of seam 7 at level -50, Nam Mau mine

Rys. 2. Schemat układu wyrobisk w strefie synkliny pokładu 7 na poziomie -50, kopalnia Nam Mau

4. Results

4.1. Assessment of the Current Status of Mine Opening and Subdivision of Coal Reserves at the Synclinal Bottom

4.1.1. Current Status of Mine Opening and Preparation of the Synclinal Bottom at the Nam Mau Coal Mine

Mine development at the Nam Mau coal mine is divided into two main parts. Coal reserves located above the natural drainage level of the area (elevation +125 m) are developed by crosscut roadways. Coal reserves located below the natural drainage level are developed by an inclined shaft extending down to level -50 m, in combination with level crosscuts. The strike longwall mining system is the dominant mining system applied at the mine. The prevailing mining technology is drilling and blasting, with roof support provided by steel arch supports and single hydraulic props. In addition, the mine operates one longwall face equipped with mechanized mining technology, using a shearer (Combai) in combination with Vinaalta powered roof supports. The current mine development and extraction levels are approaching the synclinal bottom of coal seams 9, 8, 7, and 6A within the H6 syncline. The synclinal bottoms of these seams are nearly aligned along a single axis and are vertically distributed from bottom to top in the following order: seam 6A, seam 7, seam 8, and seam 9. The mine opening scheme for coal reserves located below the natural drainage level of the Nam Mau coal mine is illustrated in Fig. 1.

(a) Mine Opening and Preparation of the Synclinal Bottom of Seam 6A at Level -60 m, Nam Mau Coal Mine

The synclinal bottom of coal seam 6A is located at level -60 m and has an elliptical shape. Mine opening for the synclinal bottom area is carried out according to the general mine development scheme of the entire mine. To access the synclinal bottom, pairs of crosscut roadways were driven at levels -40 m and -50 m. After reaching the synclinal area via the crosscut roadway at level -50 m, an along-seam roadway was driven at level -50 m. This roadway was excavated at a location where the seam dip angle is approximately 19° and was developed following the coal seam, encircling the synclinal bottom area in order to define and subdivide the synclinal boundary. At upper levels (from level -50 m upwards), the areas surrounding the syncline were prepared by pairs of upward roadways (rises) serving ventilation and haulage functions, extending from level -50 m to +125 m. After the completion of the along-seam roadway, the mining area was subdivided into several sections. The synclinal area is planned to be mined sequentially from top to bottom, with the coal at the synclinal bottom being extracted last. At present, this synclinal bottom has not yet been included in the mining plan. When mining this synclinal bottom coal, it will be necessary to drive downward roadways (dips) to the synclinal bottom in order to construct development roadways for subdividing the mining blocks, or alternatively, to access the area through mine opening from lower levels upward.

(b) Mine Opening and Preparation of the Synclinal Area of Seam 8 at Level +20 m, Nam Mau Coal Mine

The synclinal area of seam 8 at level +20 m has an elliptical shape. This area is developed and prepared by an inclined rock roadway extending from level -40 m to +18 m. From this inclined roadway, pairs of upward roadways (rises) are driven from level -3 m to +125 m. At the location identified as the synclinal bottom (level +20 m), along-seam roadways are excavated to subdivide the synclinal bottom area and the overlying levels. The positioning of these along-seam roadways ensures that the longwall faces at upper levels can transport coal using sliding chutes. The synclinal area is mined independently, following the completion of mining activities in the surrounding upper levels.

(c) Mine Opening and Preparation of the Synclinal Area of Seam 9 at Level +50 m, Nam Mau Coal Mine

The synclinal area of seam 9 has an oval shape, with a relatively large synclinal bottom. The length of the synclinal bottom along the strike direction is greater than that along the dip direction. The synclinal area is developed and prepared by an inclined coal-loading roadway extending from level -40 m to +50 m. From this roadway, two upward roadways (rises) are driven, one extending from +50 m to +88 m and the other from +35 m to +95 m. Under this development scheme, the synclinal area is subdivided into two cutting strips. The cutting strip at the synclinal bottom is mined independently and first, followed by the extraction of the upper cutting strip.

(d) Mine Opening and Preparation of the Synclinal Area of Seam 7 at Level -50 m, Nam Mau Coal Mine

The synclinal structure of seam 7 is an isometric syncline with a relatively large size, and the seam dip angle within the synclinal area is comparatively gentle. Mine opening for this area is carried out as part of the overall mine opening system.

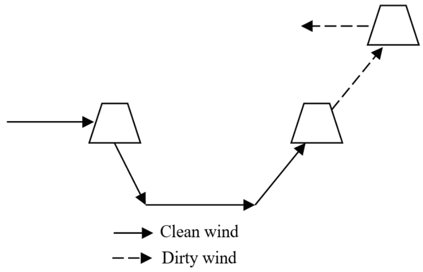

Fig.3. Ventilation scheme for the syncline bottom area
Rys. 3. Schemat wentylacji dla strefy dna synkliny

The synclinal area is developed by pairs of crosscut roadways at levels -40 m and -50 m. After the crosscut roadway at level -50 m reaches the synclinal bottom, along-seam roadways are driven at levels -50 m and -40 m to delineate and define the synclinal area. The upper levels of the synclinal area are prepared by two pairs of upward roadways (rises) extending from level -50 m to +15 m, in accordance with the development scheme shown in Fig. 2. A portion of the synclinal area is mined independently, extending from the boundary defined by the pair of ventilation and travel rises from -50 m to +125 m and the second pair of ventilation and travel rises from -50 m to +125 m. The remaining parts of the syncline are mined in conjunction with the adjacent longwall faces of the mining area. The roadway layout of the synclinal area of seam 7 is illustrated in Fig. 2.

4.1.2. Assessment of the Current Status of Mine Opening and Subdivision of the Synclinal Bottom at the Nam Mau Coal Mine
(a) Mine opening practices

Based on the results of the assessment of mine opening and subdivision for the entire mine in general, and for coal reserves at the synclinal bottoms in particular at the Nam Mau coal mine, the authors identify that mine opening for synclinal bottom coal has been implemented in several typical forms, as follows:

First type: Two-level opening system (two-level opening by crosscut roadways in combination with upward roadways driven in rock to access the synclinal bottom)

- Opening by crosscut roadways. After determining a suitable location for intersecting the synclinal bottom, development roadways are driven to access the coal seam. From the main roadways of the mine, crosscut roadways are excavated to intersect the synclinal bottom at one or two locations. In this case, seam 7 is opened by two crosscut roadways at levels -40 m and -50 m, intersecting the synclinal bottom at a single point.
- Lower-level opening by upward roadways. Mine opening is conducted from the lower level upward, whereby upward roadways are driven from the crosscut roadway of the underlying seam to access the synclinal bottom. Under this configuration, the synclinal bottoms of seams 8 and 9 are opened by pairs of rises extending from level -40 m to +18 m, while the synclinal bottom of seam 9 is accessed by a pair of rises extending from level -40 m to +35 m.

Second type: Single-level opening by downward roadways. In this case, mine opening is carried out from the upper level downward, whereby downward roadways are driven from roadways located above the synclinal bottom to reach the synclinal bottom. The synclinal bottom of seam 6A is located below level -60 m and lies beneath the crosscut roadways at levels -40 m and -50 m. Among the above opening types, each method presents specific advantages and difficulties. These aspects are discussed in detail in the following sections.

Advantages and Limitations of Synclinal Bottom Opening by a Two-Level Opening System

This opening method offers the greatest number of advantages and effectively overcomes the shortcomings of alternative opening schemes, particularly by eliminating the need for forced drainage during longwall mining. When the synclinal bottom is relatively large and flat, the opening roadway can also serve as a preparatory roadway for the synclinal bottom, providing multiple options for subdividing the area into mining panels. However, upward roadways (rises) are still required to ensure adequate ventilation of the area. In cases where the coal seam thickness at the synclinal bottom is relatively large, this method may result in higher coal losses.

Due to the geological process of coal seam formation, coal seams within the same stratigraphic column cannot have coincident synclinal bottoms. Seams formed earlier are located below those formed later. Moreover, mine development and preparation practices do not allow for the construction of crosscut roadways at many closely spaced levels to access all seams. Therefore, mines typically rely on a limited number of main crosscut roadways, from which rock rises are driven to access the remaining seams.

At the Nam Mau coal mine, the synclinal bottoms of seams 8 and 9 are accessed from the crosscut roadway at level -40 m by means of upward roadways, specifically from -40 m to +18 m for seam 8 and from -40 m to +50 m for seam 9. After reaching the seams, pairs of upward roadways were driven, including ventilation rises (-3 m to +125 m) and coal-loading rises (+17 m to +110 m) for seam 8, as well as ventilation rises (+3 m to +125 m) and coal-loading rises (+35 m to +90 m) for seam 9. Subsequently, along-seam roadways were excavated to subdivide the mining area into extraction panels.

This opening scheme facilitates effective ventilation and natural drainage of the synclinal bottom area by establishing airflow communication between two levels. Exhaust air from the longwall faces is discharged to level +125 m, thereby reducing the risk of methane (CH_4) accumulation. Water drainage within the area is achieved entirely by gravity flow along drainage ditches to level -50 m, and subsequently discharged into the mine's general drainage system. In areas with lower local depressions, pumping operations can also be implemented more efficiently.

However, this method requires the construction of inclined rock roadways (dip or rise) to access the synclinal bottom, which increases the volume of rock drivage. In addition, accurately determining the position of the synclinal bottom for access is technically challenging and may lead to increased coal loss at the synclinal bottom.

Advantages and Limitations of Synclinal Bottom Opening by Downward Roadways

In this opening method, the development roadways for accessing the underground area are located entirely within coal, which facilitates construction and results in lower roadway development costs. Drainage for the underground workings at the synclinal bottom must rely entirely on forced pumping systems, with pumps installed either within the longwall face or in development roadways located below the synclinal bottom. This requirement significantly increases drainage costs and adversely affects mining operations at the longwall face. Ventilation of the area requires leaving coal pillars to protect the upward roadways (rises) that convey contaminated air to the upper level, as illustrated in Fig. 3.

(b) Subdivision of Mining Blocks

For seam 6A, the synclinal bottom located below level -50 m has not yet been included in the mining plan. The dimensions of the synclinal bottom of seam 6A are approximately 158 m along the minor axis and 350 m along the major axis, with a geological reserve estimated at 353,440 tonnes.

For seam 7, the synclinal bottom is extensive, extending from level +125 m to -50 m, and the area also includes a small adjacent syncline at level +60 m, located near the syncline at level +20 m. As a result, the subdivision of coal reserves is relatively complex. The synclinal bottom of seam 7 has a minor axis of approximately 352 m and a major axis of 464 m, with an estimated geological reserve of 511,066 tonnes.

For the small syncline at level +20 m, which has a linear shape, the area is subdivided into two longwall faces running along the axis of the syncline, thereby forming two mining blocks located on the two limbs of the syncline. The along-seam haulage roadways of both limbs are developed in the central part of the synclinal bottom. This subdivision scheme is consistent with the structural characteristics of this syncline.

The central syncline of seam 7 is subdivided into a single independent mining block, occupying approximately one-quarter of the synclinal bottom (mining block I-7-9). The remaining areas are subdivided and integrated with mining blocks oriented in the northeast-southwest direction, forming rectangular cutting strips (from mining blocks I-7-2 to I-7-5). Due to the complex seam structure, these cutting strips alternately follow the strike direction and the dip direction. Under this subdivision scheme for seam 7, coal losses are mainly concentrated in the protective pillars between along-seam roadways. In addition, drainage for longwall faces I-7-2 to I-7-5 is expected to be highly complex.

For seam 8, the synclinal bottom is located at level +20 m and is prepared by a pair of upward roadways (rises), including a ventilation rise extending from level -3 m to +125 m and a coal-loading rise extending from level +17 m to +110 m. An along-seam ventilation roadway for mining the synclinal area is driven at level +20 m, while an along-seam haulage roadway for synclinal bottom mining is driven at level +18 m. The coal reserves above the synclinal bottom are subdivided into two mining blocks (I-8-11 and I-8-13) and are extracted by retreating toward the aforementioned rises.

This subdivision scheme is generally consistent with the structural characteristics of the syncline, and drainage conditions at the longwall faces during synclinal bottom mining are relatively favorable. However, this subdivision method results in relatively high coal losses, mainly associated with protective pillars left to safeguard the roadways within the area. The synclinal bottom of seam 8 has a minor axis of approximately 114 m and a major axis of 259 m, with an estimated geological reserve of 122,800 tonnes.

For seam 9, the synclinal bottom is located at level +50 m and is subdivided into a single independent mining block (I-9-3), which is mined independently. Two along-seam roadways are driven at level +60 m, enclosing the synclinal bottom area. This subdivision scheme is fully compatible with the geological and structural conditions of the synclinal bottom. The synclinal bottom of seam 9 has a minor axis of approximately 104 m and a major axis of 320 m, with an estimated geological reserve of 151,200 tonnes.

Overall assessment: In general, the synclinal bottoms of seams 7 to 9 are accessed from below, which facilitates effective drainage of the synclinal bottom areas. Most cutting strips are arranged along the strike direction of the coal seams to minimize coal losses (with the exception of seam 7). However, during the extraction of these cutting strips, frequent adjustments of the cutting direction are required to maintain the longwall face perpendicular to the coal seam. This operational requirement significantly limits the potential for longwall mechanization.

4.2. Assessment of the Current Status of Coal Extraction at Synclinal Bottoms

The current status of coal extraction at synclinal bottoms can be summarized as follows.

The mining system applied for synclinal bottom extraction is predominantly the strike longwall mining system with pillar subdivision. This system is currently employed at synclinal bottoms in Nam Mau Mine and Nam Khe Tam Mine. In some small synclinal areas, a dip-oriented longwall mining system is applied.

At Nam Mau Underground Coal Mine, the mining technology used for synclinal bottom extraction consists of drill-and-blast coal cutting, longwall face support using mobile steel frames and single hydraulic props, and full caving of the roof strata. The research results indicate that the selected mining system and mining technology for synclinal bottoms of coal seams at Nam Mau Mine are generally appropriate. These technologies have been applied for a relatively long period, and operational experience among miners is well established.

However, coal extraction at synclinal bottoms of coal seams is associated with several inherent difficulties, as detailed below:

- Unstable and non-uniform longwall dip angles: The dip angle of the coal seam varies along the strike direction, and the longwall face often becomes depressed at the central part of the synclinal bottom (the lowest point of the syncline). This condition causes significant difficulties in drainage and haulage within the longwall face. In addition, roadway driving in certain directions may result in repeated seam intersection or seam loss, particularly during the excavation of crosscut roadways and along-seam roadways equipped with belt conveyors or scraper conveyors. Consequently, variations in roadway gradients (including rises, declines, and longwall faces) adversely affect the layout and operation of underground equipment.

- Frequent changes in longwall face length: The length of the longwall face often varies during extraction, making it difficult to maintain the face perpendicular to the seam strike. In practice, corrective cutting toward either the headgate or tailgate side is frequently required. Correspondingly, the number of supports in the longwall face must be adjusted, which complicates production operations. Under unstable seam or roof conditions, these factors may lead to face sloughing and roof cavities.
- High coal losses at synclinal bottoms, particularly in thick coal seams. Coal losses mainly result from the necessity to leave protective pillars for roadways, roadways that do not strictly follow the seam, and longwall faces that fail to fully conform to the seam geometry.
- Negative impacts on mining system selection along the same seam: Abrupt changes in seam dip within synclinal areas affect the continuity of the applied mining system, influence the selection of mining technologies, and complicate the configuration of haulage systems within the mining district.
- Operational difficulties during synclinal mining, including challenges related to longwall face support, drainage, and ventilation, which often requires the construction of multiple ventilation structures to regulate airflow. In particular, basin-shaped synclinal bottoms pose severe drainage difficulties for both longwall faces and development roadways and present a potential risk of water inrush to adjacent mining areas.
- Non-standard subdivision and preparation of mining blocks at synclinal bottoms compared with the two limbs of the syncline. In such cases, the size and shape of mining blocks are largely dictated by the subdivision scheme adopted for the synclinal bottom. If conventional rectangular panels are applied, irregular coal zones at the synclinal bottom may remain unmined, leading to an increased coal loss ratio.

4.3. Assessment of the Current Status of Haulage in Coal Extraction at Synclinal Bottoms

4.3.1. Current Status of Haulage during Coal Extraction at Synclinal Bottoms

(1) Haulage during development roadway driving

Development roadways in synclinal bottom areas may be driven either within coal seams or in surrounding rock, depending on the selected development approach. At present, mines may adopt either drill-and-blast technology or roadheader (combai) excavation technology for roadway driving.

Haulage operations in development roadways consist of two main stages: loading and transportation. Depending on the excavation technology and the location of the roadway relative to the coal seam, loading can be carried out either mechanically (commonly applied in rock roadways or roadways with large cross-sections) or manually (typically applied in coal roadways with small cross-sections).

After loading, rock and coal are transferred onto haulage equipment installed behind the face. Currently, two main haulage systems are commonly used in underground mines:

- Electric locomotive haulage, primarily applied in rock roadways. This is the dominant haulage method for development operations in most mines.
- Belt conveyor haulage, mainly used in roadways driven within coal seams.

In addition to these systems, armoured face conveyors (AFCs) are sometimes employed for short roadway sections or as transfer devices feeding mine cars or belt conveyors.

(2) Haulage within the longwall face

At synclinal bottoms, the dip angle of the longwall face is generally small (less than 20°). Therefore, coal haulage within the longwall face is typically conducted using armoured face conveyors, particularly in synclinal bottoms of relatively large size. Coal is then transferred to haulage equipment installed in along-seam roadways and trasported into the main haulage system of the mine.

4.3.2. Assessment of the Current Status of Haulage during Coal Extraction at Synclinal Bottoms

Overall, haulage operations in synclinal bottom areas are adequately organized, and no significant coal accumulation or congestion causing production interruptions has been observed. Haulage during development roadway driving is mainly performed using a combination of electric locomotive systems and belt conveyors.

In synclinal areas where the longwall face dip angle exceeds 20°, sliding chutes are commonly used for coal transport. Conversely, in longwall faces with dip angles less than 20°, armoured face conveyors are applied, particularly in large synclinal bottoms where face dip angles are often less than 10°. These haulage systems generally meet operational requirements in terms of transport capacity and working conditions.

However, coal extraction at synclinal bottoms is associated with several haulage-related challenges, including:

- Non-uniform longwall gradients: The longwall face often exhibits a depressed profile at the center of the synclinal bottom (e.g., at the synclinal bottom of Seam 9 in Nam Mau Mine). As a result, armoured face conveyors tend to bend, increasing the likelihood of mechanical failures during operation.
- Multi-stage haulage systems: Haulage in synclinal bottom areas often requires multiple transfer stages, which complicates the synchronization and integration of haulage equipment and reduces overall system efficiency.

4.4. Assessment of the Current Status of Ventilation and Drainage during Coal Extraction at Synclinal Bottoms

4.4.1. Assessment of the Current Status of Ventilation during Coal Extraction at Synclinal Bottoms

Tab. 1. Comparison of development schemes, mining systems, and recovery indicators at synclinal bottoms in selected coal-producing countries [9, 11–14]
Tab. 1. Porównanie schematów rozwoju, systemów eksploatacji i wskaźników uzysku w strefach dna synklin w wybranych krajach produkujących węgiel [9, 11–14]

Criteria	Vietnam (Nam Mau mine)	China	Poland/Germany	Australia
Main development scheme	Two-level development using crosscut roadways and raises	Multi-level development	Optimized multi-level development	Multi-level development with advanced planning
Mining system	Strike longwall mining system	Highly mechanized longwall mining	Mechanized longwall mining	High-capacity longwall mining
Level of mechanization	Moderate	High	High	Very high
Recovery ratio (%)	75-85%	85-92	88-93	90-95
Coal loss (%)	10 - 20%	5 - 10	5 - 8	< 5
Pre-drainage measures	Not widely applied	Widely applied	Widely applied	Widely applied

(1) Current status of ventilation during coal extraction at synclinal bottoms

a) Ventilation of development roadways

During coal extraction at synclinal bottoms, underground coal mines have generally maintained and ensured safe ventilation conditions during roadway development.

The main ventilation method applied for development roadways in synclinal bottom areas is forcing ventilation. For long development roadways, some mining companies have adopted series connections of auxiliary fans with small to medium capacities. Recently, the application of multi-stage auxiliary fan systems for ventilating long roadways has demonstrated higher effectiveness.

In forcing ventilation systems, rubber-coated fabric ventilation ducts are used to deliver fresh air to the working face. Duct installation and extension are carried out in accordance with the advance rate of the heading face, and the distance between the duct outlet and the face is always maintained within the limits specified by current regulations.

The concentrations of toxic and hazardous gases are closely monitored, and the air volume supplied to the heading face meets the calculated ventilation requirements for each roadway. Mines have implemented various measures to control hazardous gas concentrations, particularly methane (CH_4), including portable gas detectors, automatic gas monitoring and alarm systems, and other gas mitigation methods.

b) Ventilation of longwall faces

Ventilation for longwall faces in synclinal bottom areas is provided through the mine-wide ventilation system. The airflow direction within longwall faces complies with current safety regulations. The airflow quantity supplied to each longwall face meets the calculated ventilation demand; this is regulated through ventilation doors or auxiliary fans where necessary.

In some mines, ventilation crossings (air bridges) are installed to separate fresh air streams from return air streams. Air velocity within the longwall faces remains within permissible limits, ensuring safe and stable ventilation conditions during coal extraction.

(2) Assessment of the Current Status of Ventilation during Coal Extraction at Synclinal Bottoms

The ventilation solutions applied during roadway development and longwall extraction have effectively ensured operational safety. Concentrations of toxic and hazardous gases remain within permissible limits, while air velocity and airflow direction in roadways comply with current regulations.

The microclimatic conditions within underground roadways satisfy required criteria, including oxygen content, concentrations of toxic and hazardous gases, air humidity, and air temperature. The ventilation system is continuously maintained, ensuring uninterrupted production without ventilation-related delays.

However, coal extraction at synclinal bottoms often requires the use of multiple ventilation structures (such as ventilation doors and air bridges) to regulate airflow distribution among consumption points and to separate fresh air from return air streams. As a result, return air roadways are typically long, making their maintenance and protection more difficult and increasing overall mining costs. Air leakage in synclinal bottom areas is significant, occurring through ventilation structures and mined-out areas. Consequently, the calculation, distribution, and regulation of airflow become more complex and challenging.

4.4.2. Assessment of the Current Status of Drainage during Coal Extraction at Synclinal Bottoms

(1) Current status of drainage during coal extraction at synclinal bottoms

a) Drainage during development roadway driving

Drainage during the driving of development roadways in synclinal bottom areas is mainly achieved through drainage ditch systems. The cross-sectional area of drainage ditches is designed to accommodate the total water inflow during roadway excavation, typically ranging from 0.15 to 0.30 m². Drainage ditches are installed along the sidewalls of roadways, and in some roadways, precast concrete drainage channels are used. Along the length of drainage ditches, sedimentation sumps are arranged at intervals of approximately 150–200 m.

An analysis of development and preparation practices for synclinal bottom coal indicates that no mines have applied pre-drainage measures prior to roadway excavation and coal extraction in synclinal bottom areas.

b) Drainage in longwall faces

Drainage at longwall faces located at synclinal bottoms is predominantly conducted by gravity flow into along-seam roadways. In some mines, along-seam roadways are arranged below the synclinal bottom level to facilitate natural drainage. However, in several synclinal areas of Nam Mau Coal Mine, along-seam roadways are located at the same elevation as the synclinal bottom, resulting in water accumulation within the longwall face.

In these longwall faces, Nam Mau Mine has adopted water collection sumps, followed by pumping systems to discharge water into adjacent roadways. From there, water is conveyed to central storage reservoirs through drainage ditch systems installed in along-seam roadways.

Due to the absence of pre-drainage measures prior to extraction, water tends to accumulate within longwall faces and along-seam roadways, particularly where roadway gradients are insufficient. This accumulation poses significant challenges to mining operations and adversely affects production efficiency.

(2) Assessment of the Current Status of Drainage during Coal Extraction at Synclinal Bottoms

Drainage during the driving of development roadways is carried out using drainage ditch systems, which are capable of fully discharging the water inflow generated during roadway excavation.

Drainage operations in longwall faces are generally well managed. In the synclinal areas currently being mined, the applied development schemes and mining field subdivision methods allow gravity drainage, and pumping is not required for water removal within the longwall faces. Water released in the longwall faces flows naturally into the mine-wide drainage system.

The prediction and assessment of water inrush hazards during roadway driving and coal extraction are regularly conducted throughout the mining process. As a result, no incidents of water or mud inrush have occurred at synclinal bottoms.

However, as synclinal bottoms represent the lowest topographic zones within the mining area, they naturally serve as points of water accumulation. In addition, roadways in these areas often have small and uneven gradients, leading to localized water accumulation at certain locations, particularly within longwall faces and along-seam roadways. Consequently, water collection recesses in along-seam roadways and sumps within longwall faces must be constructed, and pumping systems are locally employed to remove accumulated water.

5. Discussion

The results indicate that the access development and extraction solutions applied at synclinal bottoms in Nam Mau coal mine are generally appropriate under the existing geological and technical conditions. The two-level access scheme using crosscuts and rock raises facilitates production organization, particularly in ventilation and drainage. This configuration enables relatively independent airflow routes and allows gravity drainage from synclinal bottoms to lower mine levels. For large synclines, such as those in seams 8 and 9, independent mining layouts help reduce operational interference between panels, thereby improving safety and production stability. The longwall mining system along strike, combined with drilling-and-blasting extraction and support using single hydraulic props or frames, remains a conventional yet suitable solution under the current technological level of the mine.

Despite being generally appropriate, the applied solutions exhibit several notable limitations. First, extensive rock drivage significantly increases development volume, leading to higher initial investment costs and longer preparation periods. Second, drilling-and-blasting extraction restricts productivity improvement and complicates coal loss control in highly deformed seam zones at synclinal bottoms. Current drainage relies mainly on gravity flow supplemented by localized pumping, while advance drainage measures are not widely implemented. Consequently, the risk of sudden water inflow remains, particularly during roadway development and early-stage extraction at synclinal bottoms.

Compared with underground coal mines in China, Poland, Germany, and Australia, the two-level access strategy at Nam Mau follows a similar conceptual approach, yet the adoption of advanced technologies remains limited. In China, synclinal bottom mining commonly integrates multi-level access with detailed geological-hydrogeological modeling and advance drainage drilling, substantially reducing water pressure and coal losses [11]. Polish and German mines emphasize panel geometry optimization and numerical modeling to control deformation and roof stability [12, 13].

Quantitative comparison indicates that coal recovery rates in Vietnamese mines (approximately 75–85%) are lower than those in highly mechanized international operations (85–95%), while pillar-related coal losses are higher. These differences primarily result from lower mechanization and automation levels, as well as the limited integration of predictive and modeling tools in mine design and operation [9].

Performance differences in synclinal bottom mining arise not only from mechanization levels but from the way access schemes, hydrogeological conditions, and panel geometry co-adapt to local structures. Two-level opening systems (crosscuts combined with rock raises) establish independent ventilation circuits and gravity-driven drainage, yet they increase rock drivage volumes and demand tighter positional tolerances at structural lows, which restrict the continuity of mechanized longwalls. Conversely, single-level downward openings reduce development costs in coal but shift the burden to forced pumping and pillar protection, redistributing losses and amplifying operational variability.

The 10–15 percentage point gap in recovery rates is largely explained by protective pillars left due to misaligned roadways, variable longwall lengths caused by basin-shaped synclines, and leakage of airflow through mined-out voids, which raises ventilation demand. Therefore, the upgrade pathway should emphasize advance hydrogeological probing and pre-drainage in low-lying zones, parametric redesign of panel geometry to minimize directional corrections, and staged mechanization supported by pilot panels. Clear KPI-based monitoring covering pillar losses, AFC reliability, and drainage costs will be essential. This approach aligns with Vietnam's investment capacity and workforce conditions, while narrowing the gap with international operational benchmarks.

6. Conclusion

This study provides a systematic assessment of mining activities at synclinal bottoms in underground coal mines of the Quang Ninh coal basin, with Nam Mau mine serving as a representative case. The results confirm that complex geological and structural conditions, particularly the vertical misalignment of synclinal bottoms among coal seams, are the primary factors constraining mine opening, ventilation, drainage, and mechanization efficiency. The currently applied opening schemes, mainly the two-level opening system using crosscut roadways and raises, as well as the single-level opening by downwards roadways, exhibit distinct advantages and limitations. Among them, the two-level opening system demonstrates clear superiority in terms of ventilation effectiveness and gravity-driven drainage, thereby enhancing operational safety at synclinal bottoms, although it requires higher rock drivage volumes and careful determination of synclinal bottom positions to limit coal losses. Field subdivision and longwall layout at the synclinal bottoms of seams 7, 8, and 9 are generally compatible with local structural characteristics; however, significant coal losses at protective pillars and reduced adaptability to mechanized longwall systems remain evident. The longwall mining system along strike combined with drill-and-blast technology remains suitable under complex geological conditions, but recovery rates and mechanization levels are still lower than those reported in international practice. Comparative analysis with underground coal mines in China, Poland, Germany, and Australia highlights the need for more optimized multi-level opening layouts, pre-drainage measures, and higher degrees of mechanization to improve recovery efficiency and reduce resource losses. Overall, this study offers a practical and scientific basis for optimizing synclinal bottom mining strategies in Vietnamese underground coal mines and supports future research toward safer and more efficient deep mining operations.

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Ocena aktualnego stanu działalności górniczej w strefie dna synkliny w podziemnej kopalni węgla Nam Mau, Wietnam

Eksploatacja w strefach dna synklin stanowi poważne wyzwanie techniczne dla podziemnych kopalń węgla w zagłębiu węglowym Quang Ninh ze względu na złożone struktury geologiczne, wysokie ryzyko akumulacji wody i koncentracji gazów oraz zwiększone straty węgla. Niniejsze opracowanie przedstawia systematyczną ocenę schematów otwarcia kopalni, podziału pól eksploatacyjnych, metod wydobycia, wentylacji, transportu i odwadniania stosowanych w strefach dna synklin, na przykładzie podziemnej kopalni węgla Nam Mau. Wyniki wskazują, że pionowe przesunięcia dna synklin pomiędzy pokładami węgla są głównym ograniczeniem wpływającym na rozwój kopalni i organizację produkcji. Aktualnie stosowane schematy otwarcia, obejmujące dwupoziomowy system otwarcia z przecznicami i chodnikami wznoszącymi oraz jednopoziomowe otwarcie poprzez chodniki nachylone w dół, wykazują wyraźne zalety techniczne i ograniczenia. W szczególności dwupoziomowy system otwarcia zapewnia lepsze warunki wentylacyjne i grawitacyjne odwadnianie, poprawiając bezpieczeństwo pracy w strefach dna synklin, choć wymaga zwiększonego drążenia skał i starannego usytuowania w celu ograniczenia strat węgla. Podział pól i układ ścian eksploatacyjnych w strefach dna synklin są zasadniczo zgodne z lokalnymi cechami strukturalnymi; jednak wskaźniki odzysku węgla i poziom mechanizacji pozostają niższe niż międzynarodowe standardy. Analiza porównawcza z podziemnymi kopalniami węgla w Chinach, Polsce, Niemczech i Australii podkreśla potrzebę optymalizacji wielopoziomowych układów otwarcia, zastosowania środków wstępnego odwadniania oraz wyższego stopnia mechanizacji. Wyniki dostarczają naukowych podstaw do optymalizacji strategii eksploatacji w strefach dna synklin w wietnamskich kopalniach podziemnych i wspierają przejście w kierunku bezpieczniejszej i bardziej efektywnej głębokiej eksploatacji.

Słowa kluczowe: *eksploatacja w strefie dna synkliny, podziemna kopalnia węgla, system otwarcia kopalni, eksploatacja ścianowa, wentylacja i odwadnianie*