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

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Abstract: ***Mining coal reserves at synclinal bottoms is one of the most technically challenging operations in underground coal mining due to unfavorable geological structures, complex hydrogeological conditions, and high risks of coal loss. In the underground coal mines of Quang Ninh Province, Viet Nam, many mines are currently approaching or entering the synclinal bottoms of multiple coal seams as shallow reserves become depleted. This paper presents a comprehensive assessment of the current status of mine opening schemes and coal reserve subdivision at synclinal bottoms, based on detailed case studies of the Nam Mau and Nam Khe Tam underground coal mines. The study analyzes applied mine opening methods, roadway layouts, subdivision of mining blocks, and associated advantages and limitations. The results show that two-level opening systems combining crosscut roadways and rock rises provide superior conditions for ventilation and natural drainage, thereby improving safety during synclinal bottom mining. However, this approach is associated with increased rock drivage and potential coal losses in thick seams. Single-level opening by downward roadways reduces development costs but leads to high drainage and ventilation complexity. The findings provide a scientific basis for optimizing mine opening and coal reserve subdivision strategies for synclinal bottom mining in Vietnamese underground coal mines.***

Keywords: Synclinal bottom, mine opening, coal reserve subdivision, underground coal mining, Quang Ninh Province

1. Introduction

In recent years, the integration of scientific advancements has shaped underground coal mining is increasingly shifting toward deeper and more structurally complex zones as shallow and intermediate coal reserves become depleted worldwide [1]. Among these zones, synclinal bottoms represent one of the most unfavorable geological settings for coal extraction. The basin-shaped geometry of synclinal structures promotes the accumulation of groundwater and methane, while variations in seam dip and thickness complicate mine development, ventilation, drainage, and production organization [2].

Mine opening and subdivision of coal reserves play a decisive role in determining the safety, technical feasibility, and economic efficiency of coal extraction at synclinal bottoms [3]. Inappropriate opening schemes may result in forced drainage systems, complex ventilation networks, excessive coal losses, and increased operational risks. Conversely, well-designed opening and subdivision solutions can significantly improve natural drainage conditions, stabilize airflow patterns, and enhance resource recovery. Therefore, the selection of rational mine opening systems and subdivision strategies is considered a key technical challenge in synclinal bottom mining.

1.1 International Research Background

Internationally, mining at synclinal and structurally complex zones has been studied mainly in coalfields of some countries such as China [4], Poland [5], Germany [6], etc. Previous studies have focused on the optimization of mine opening layouts, multi-level development systems, and panel orientation in folded coal seams [7]. Research results indicate that opening synclinal bottoms from lower levels using crosscuts and rock rises can significantly improve drainage efficiency and ventilation stability [8]. Some authors have also emphasized the importance of adapting panel geometry to fold axes in order to reduce coal loss and stress concentration [9].

However, most international studies address general folded or inclined seam conditions, while detailed assessments of mine opening and coal reserve subdivision specifically at synclinal bottoms remain limited. Furthermore, geological and mining conditions in Quang Ninh coalfields differ significantly from those of major coal-producing countries due to thinner seams, higher tectonic complexity, and strong hydrogeological influences [10].

1.2 Research Status in Viet Nam

In Viet Nam, underground coal mining in Quang Ninh Province has gradually entered synclinal bottom zones since the early 2000s. Practical solutions for mine opening and coal extraction at synclinal bottoms have been implemented at several mines, including Nam Mau, Nam Khe Tam, Khe Cham, and Vang Danh. These solutions mainly include two-level opening systems with rock rises and single-level downward opening from upper horizons [11].

Most existing Vietnamese studies concentrate on individual technical aspects such as ventilation, drainage, or production safety at synclinal structures. Comprehensive evaluations of mine opening systems and coal reserve subdivision at synclinal bottoms are still scarce. In many cases, applied solutions are based primarily on practical experience rather than systematic assessment of geological-structural conditions and their influence on opening efficiency and coal loss [11].

1.3 Research Gaps

Despite the growing importance of synclinal bottom mining, several critical research gaps remain:

- Lack of integrated assessment of mine opening and coal

reserve subdivision at synclinal bottoms;
- Insufficient analysis of the relationship between synclinal geometry and opening efficiency;
- Limited comparative evaluation of different opening systems applied in Vietnamese underground coal mines;
- Absence of a clear scientific basis for selecting optimal subdivision schemes at synclinal bottoms.

These gaps highlight the need for a comprehensive study that combines geological analysis with practical mining experience.

1.4 Objectives of the Study

The main objective of this study is to assess the current status of mine opening and subdivision of coal reserves at synclinal bottoms in underground coal mines of Quang Ninh Province. Specifically, the study aims to: (1) Analyze geological and structural characteristics of synclinal bottoms affecting mine opening; (2) Evaluate existing mine opening systems applied at synclinal bottoms; (3) Assess current coal reserve subdivision schemes and associated coal losses; (4) Identify technical advantages, limitations, and key issues requiring optimization. The Nam Mau and Nam Khe Tam underground coal mines are selected as representative case studies to provide a scientific basis for improving synclinal bottom mining practices in Viet Nam.

2. Study Area and Methodology

2.1 Study Area

The study focuses on two representative underground coal mines, located in the main coal-producing regions of Quang Ninh Province, Viet Nam, namely the Nam Mau and Nam Khe Tam underground coal mines, which are characterized by complex geological structures and well-developed synclinal bottoms [11]. Nam Mau Mine is situated in the Uong Bi-Dong Trieu coal basin, where multiple coal seams are strongly affected by folding and faulting, forming several major synclinal structures such as H4, H6, and H10. At present, mining activities at Nam Mau are approaching the synclinal bottoms of seams 6A, 7, 8, and 9 within the H6 syncline, where the synclinal bottoms of different seams are vertically distributed along a common structural axis, creating significant challenges for mine opening, ventilation, drainage, and coal reserve subdivision. In contrast, Nam Khe Tam Mine is located in the Cam Pha coal region, where synclinal structures are developed in seams 9, 11, 12, and 18, with both narrow and wide synclinal bottoms already partially or fully extracted. The mining experience accumulated at Nam Khe Tam provides valuable practical data for assessing the effectiveness of different mine opening and subdivision schemes under synclinal bottom conditions. The selection of these two mines allows for a representative evaluation of synclinal bottom mining practices under varying geological, structural, and hydrogeological conditions in Vietnamese underground coal mines [11].

2.2 Research Methodology

This study adopts a qualitative and comparative research methodology based on the analysis of actual mining practices at synclinal bottoms in the selected mines. The research process includes a detailed examination of mine development schemes, geological cross-sections, and roadway layouts to identify the applied mine opening methods at synclinal bottoms. Special attention is given to the spatial relationship between synclinal geometry and the arrangement of crosscuts, rock rises, downward roadways, and along-seam entries. In addition, coal reserve subdivision schemes are analyzed and compared across different seams and mines to evaluate their technical rationality, adaptability to synclinal geometry, and impact on coal recovery. The study also assesses technical advantages, limitations, and coal loss mechanisms associated with each opening and subdivision approach, particularly under conditions of water accumulation and variable seam dip. All analyses are based on documented mine layouts, operational records, and technical reports, ensuring that the assessment reflects real production conditions rather than theoretical assumptions.

3. Geological and Structural Characteristics of Synclinal Bottoms

Synclinal bottoms in the studied underground coal mines exhibit a set of geological and structural characteristics that strongly control mine opening and coal extraction conditions. These synclinal bottoms typically display basin-shaped or elliptical geometries, often elongated along the seam strike, with the smallest dip angles occurring at the synclinal axis and increasing gradually toward the limbs. Due to stratigraphic succession and tectonic deformation, the synclinal bottoms of adjacent coal seams are usually vertically offset rather than coincident, resulting in significant differences in elevation between synclinal axes across seams. This vertical misalignment complicates mine opening planning, as it is often impractical to access multiple synclinal bottoms using crosscuts at the same level. Furthermore, synclinal bottoms are frequently associated with fractured rock zones and water-bearing strata, making them natural accumulation areas for groundwater and increasing the risk of water inflow during mining. These combined characteristics necessitate the use of specialized mine opening solutions, such as rock rises or downward roadways, and require careful consideration of drainage and ventilation conditions. Consequently, the geological and structural features of synclinal bottoms constitute the fundamental controlling factors that govern the selection and effectiveness of mine opening systems and coal reserve subdivision schemes.

Based on the above geological and structural characteristics, it is evident that the basin-shaped geometry, vertical misalignment of synclinal bottoms among coal seams, and strong hydrogeological influence impose fundamental constraints on mine opening strategies. These controlling factors necessitate the adoption of specialized opening systems capable of ensuring effective access, stable ventilation, and reliable drainage at synclinal bottoms. Consequently, the following section evaluates the current status of mine opening systems that have been practically applied in the studied mines under such complex synclinal conditions.

4. Current Status of Mine Opening at Synclinal Bottoms

4.1 Two-Level Opening System

The two-level opening system is the most widely applied approach for accessing synclinal bottoms at Nam Mau Underground Coal Mine, particularly for seams 7, 8, and 9, where synclinal bottoms are located above existing lower-level crosscuts. In this system, main crosscut roadways are developed at lower horizons, typically at depths of −40 m to −50 m, from which rock rises are driven upward to intersect the coal seams at or near their synclinal axes. After reaching the seam, paired rises for ventilation and coal transportation are constructed, followed by along-seam roadways to delineate mining blocks and prepare longwall panels. This opening configuration establishes direct airflow communication between two levels, significantly improving ventilation stability while simultaneously enabling gravity-assisted drainage toward lower horizons, thereby reducing dependence on pumping systems. Moreover, the two-level system provides flexibility in subdividing large synclinal bottoms into independent or semi-independent mining blocks. However, this approach requires a substantial volume of rock drivage, leading to higher development costs, and demands precise geological control to accurately locate synclinal axes. In thick seams, additional coal losses may occur due to the necessity of protective pillars and the spatial arrangement of roadways near the synclinal bottom.

4.2 Single-Level Opening by Downward Roadways

Single-level opening by downward roadways has been applied mainly to seam 6A at Nam Mau Mine, where the synclinal bottom lies below the existing crosscut levels, making upward access from lower horizons technically impractical. In this method, downward roadways are driven directly along the coal seam from upper levels toward the synclinal bottom, which allows all development workings to be excavated within coal. This reduces rock excavation and lowers initial development costs compared to the two-level opening system. However, the absence of a lower-level outlet means that drainage relies entirely on pumping systems, increasing operational complexity and cost. Ventilation is also more challenging, as upward airways must be protected by coal pillars, resulting in longer airflow paths and higher resistance. These factors increase both safety risks and operating expenses, particularly under conditions of high water inflow and methane emission commonly associated with synclinal bottoms.

5. Subdivision of Coal Reserves at Synclinal Bottoms

Subdivision of coal reserves at synclinal bottoms in the studied mines varies significantly depending on syncline size, seam thickness, and opening configuration. At Nam Mau Mine, the synclinal bottom of seam 6A located below -50 m remains largely unmined, with estimated reserves exceeding 350,000 tonnes, highlighting the limitations of current opening schemes for deep synclinal zones. In seam 7, a large and structurally complex synclinal bottom has been subdivided using a combination of independent mining blocks and integrated panels, which, while technically feasible, results in considerable coal losses due to extensive protective pillars and irregular panel geometry. Seam 8 represents a medium-sized synclinal bottom that has been subdivided into retreating longwall panels oriented generally along the seam strike, providing a relatively balanced solution between geological adaptability and production efficiency, albeit with moderate coal losses. In contrast, the synclinal bottom of seam 9 has been subdivided as a single independent mining block, demonstrating the most rational and efficient subdivision scheme among the studied cases, with reduced coal loss and simplified production organization. Overall, existing subdivision schemes tend to follow seam strike to minimize losses; however, frequent adjustments in panel orientation are often required to maintain favorable longwall geometry relative to the synclinal axis, which limits the application of high-level mechanization and affects production continuity.

6. Discussion

The assessment of mine opening and coal reserve subdivision at synclinal bottoms reveals that geological and structural characteristics constitute the primary controlling factors governing the effectiveness of applied mining solutions. The basin-shaped geometry of synclinal bottoms, combined with the vertical misalignment of synclinal axes among adjacent coal seams, fundamentally limits the applicability of conventional opening systems commonly used in gently inclined or uniformly dipping seams. Under such conditions, mine opening strategies that do not adequately consider natural drainage potential and ventilation pathways inevitably lead to increased operational complexity and safety risks.

The comparative analysis indicates that two-level opening systems exhibit clear technical advantages for medium to large synclinal bottoms, particularly in terms of drainage and ventilation. Opening synclinal bottoms from lower levels enables gravity-assisted water flow toward sump horizons, thereby reducing reliance on continuous pumping during extraction. At the same time, the establishment of airflow connections between two levels contributes to more stable ventilation conditions and improved gas control. These findings are consistent with international experience reported in folded coalfields, where multi-level access has been shown to enhance both safety and production stability. However, the increased volume of rock drivage required by two-level systems represents a significant economic drawback, especially in mines characterized by hard surrounding rock and limited development capacity. In addition, inaccuracies in predicting the exact position of synclinal axes may lead to suboptimal roadway placement and increased coal losses in thick seams.

Single-level opening by downward roadways demonstrates certain economic advantages during the development stage due to reduced rock excavation and simpler construction. Nevertheless, the results show that this approach is associated with substantial technical limitations when applied to synclinal bottoms. The absence of lower-level outlets forces full dependence on pumping systems, which not only increases operating costs but also heightens vulnerability to water-related incidents. Ventilation systems under single-level opening are often constrained by long airflow routes and the necessity to leave protective coal pillars, resulting in higher resistance and increased leakage. These shortcomings become more pronounced as mining advances deeper into synclinal bottoms, suggesting that single-level opening is only suitable for small synclines or short-term extraction scenarios.

The analysis of coal reserve subdivision further underscores the profound and multi-layered interaction between geological conditions and mining organization. Large synclinal bottoms, when subdivided into numerous mining blocks, consistently exhibit elevated coal losses, primarily because irregular panel geometries force the creation of extensive protective pillars and complicate roadway alignment. These irregularities not only reduce recovery efficiency but also cause operational instability, as panel boundaries often fail to correspond with natural seam structures. In contrast, medium-sized synclinal bottoms or synclinal axes that are clearly defined and treated as independent mining blocks have demonstrated greater rationality and technical coherence. The case of seam 9 at Nam Mau Mine illustrates how a more compact and structurally consistent synclinal bottom can be mined with fewer protective pillars, reduced coal losses, and more predictable panel geometry. This comparison suggests that subdivision strategies should emphasize geological adaptability and structural compatibility rather than rigid adherence to conventional panel layouts, which may not reflect the complexity of synclinal formations. Nevertheless, frequent adjustments in longwall orientation, required to accommodate the curvature and variability of synclinal geometry, continue to restrict the application of advanced mechanization technologies and negatively affect production continuity, equipment utilization, and overall efficiency. Table 1 provides a qualitative comparison of mine opening systems at synclinal bottoms, highlighting these trade-offs.

Overall, the discussion confirms that current mine opening and subdivision practices in Vietnamese underground coal mines achieve basic technical feasibility but remain far from optimal in terms of maximizing resource recovery and ensuring long-term operational efficiency. A critical limitation lies in the absence of integrated design approaches that simultaneously account for geological variability, drainage requirements, ventilation pathways, and subdivision strategies. Addressing this gap requires systematic optimization of opening layouts tailored to synclinal geometry and seam-specific conditions, moving beyond reliance on experience-based or incremental solutions. Based on the findings of this study, several technical recommendations and directions for future research are proposed. First, mine opening design at synclinal bottoms should prioritize access from lower levels wherever geological and infrastructural conditions allow, thereby maximizing natural drainage potential and improving ventilation efficiency. Optimization of two-level opening systems should focus on minimizing unnecessary rock drivage through precise geological modeling, enhanced prediction of synclinal axes, and better integration of roadway positioning. Second, coal reserve subdivision strategies must be adapted to the geometry of synclines rather than applying conventional panel layouts, with particular emphasis on reducing protective pillars and mitigating coal losses at synclinal axes. Third, integrated planning frameworks that simultaneously consider geology, mine opening, ventilation, drainage, and production organization should be developed to strengthen overall system performance and resilience.

Future research should expand the current qualitative assessment by incorporating quantitative analyses of ventilation efficiency, drainage capacity, and coal loss under different opening and subdivision scenarios. Numerical modeling and simulation techniques could be employed to evaluate alternative opening layouts, optimize roadway arrangements, and test mechanization strategies in complex synclinal structures. Moreover, further studies should examine the applicability of pre-drainage measures, advanced monitoring technologies, and predictive hydrogeological modeling to reduce water-related risks and improve safety. Expanding the empirical database to include additional underground coal mines with diverse geological conditions would contribute to establishing more generalized and scientifically grounded design guidelines for synclinal bottom mining, thereby supporting the transition toward safer, more efficient, and more sustainable deep mining operations in Vietnam and beyond.

Table 1: Comparative characteristics of mine opening systems at synclinal bottoms

Mine opening system	Access mode and technical characteristics	Main advantages	Main limitations and applicability
Two-level opening system	Access to synclinal bottoms is achieved from lower-level crosscut roadways through rock rises or inclined rock roadways, establishing direct connections between two levels. This configuration enables inter-level ventilation and gravity-assisted drainage toward lower horizons.	Provides high ventilation efficiency and effective natural drainage, resulting in improved operational safety. Particularly suitable for medium to large synclinal bottoms with complex hydrogeological conditions.	Requires a large volume of rock drivage and high initial investment costs. Accurate determination of synclinal axes is essential; otherwise, increased coal losses may occur, especially in thick coal seams.
Single-level opening by downward roadways	Synclinal bottoms are accessed from upper levels by downward roadways driven within the coal seam, allowing all development workings to be constructed in coal without lower-level outlets.	Reduces rock excavation and lowers initial development costs compared with two-level opening systems.	Drainage relies entirely on forced pumping, and ventilation systems are more complex with long airflow paths and the need for protective coal pillars. Operating costs and safety risks increase with mining depth. This system is mainly applicable to small synclinal bottoms or relatively favorable hydrogeological conditions.
Overall	---	Two-level opening systems	Single-level opening systems are economically

comparison		offer superior technical performance and safety in synclinal bottom mining.	attractive at the development stage but exhibit lower long-term sustainability. The selection of an opening system should be based on syncline scale, geological-hydrogeological conditions, and long-term mining objectives.

7. Conclusion

This study provides a comprehensive assessment of the current status of mine opening and coal reserve subdivision at synclinal bottoms in underground coal mines of Quang Ninh Province, based on representative case studies from the Nam Mau and Nam Khe Tam mines. The results confirm that synclinal bottoms constitute structurally and hydrogeologically unfavorable zones where conventional mine opening solutions are no longer sufficient to ensure optimal safety and efficiency. The basin-shaped geometry of synclinal structures, vertical misalignment of synclinal axes among coal seams, and frequent association with water-bearing strata jointly impose fundamental constraints on opening layouts and subdivision strategies.

The analysis demonstrates that two-level opening systems offer superior technical performance for medium to large synclinal bottoms by enhancing natural drainage and stabilizing ventilation through inter-level airflow connections. These advantages significantly reduce dependence on forced pumping and complex ventilation control, thereby improving operational safety during extraction. However, the economic and technical drawbacks of increased rock drivage and potential coal losses in thick seams highlight the necessity for careful optimization of roadway placement and pillar design. In contrast, single-level opening by downward roadways, while economically attractive at the development stage, exhibits inherent limitations related to drainage, ventilation complexity, and long-term sustainability, restricting its applicability to small synclines or short extraction horizons.

Regarding coal reserve subdivision, the study reveals that subdivision schemes closely aligned with synclinal geometry are more effective in reducing coal loss and simplifying production organization. Treating well-defined synclinal bottoms as independent mining blocks emerges as a rational solution, whereas excessive fragmentation of large synclinal bottoms leads to increased coal loss and operational inefficiency. Overall, the findings indicate that existing practices in Vietnamese underground coal mines ensure basic feasibility but remain suboptimal in terms of resource recovery and long-term performance, underscoring the need for integrated and geology-driven design approaches.

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