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TECHNICAL SOLUTIONS FOR SAFE AND EFFICIENT MINING OF DEEP COAL ACCUMULATION ZONES IN THE QUANG NINH BASIN (VIETNAM)

Purpose. To develop and validate technical solutions for safe and efficient coal extraction at the bottom of deep coal accumulation zones characterized by complex geological and hydrogeological conditions. The research addresses key challenges such as high groundwater pressure, faulted structures, and reduced rock mass stability, using the Nam Mau and Nam Khe Tam underground mines as representative case studies.

Methodology. The research methodology combined geological–hydrogeological data analysis, spatial database development, three-dimensional numerical modeling, expert evaluation, and pilot field validation. Based on structural and hydrological characteristics, two access systems were designed and implemented: a dual-level access layout for large and deep accumulation zones (Nam Mau Mine), and an optimized single-level access system for smaller and moderately inclined seams (Nam Khe Tam Mine).

Findings. Field implementation demonstrated the technical effectiveness of the proposed systems. At Nam Mau Mine, the dual-level layout reduced groundwater accumulation by 35 %, increased ventilation efficiency by 1.45 times, and eliminated water inrush incidents during the testing period. At Nam Khe Tam Mine, the optimized single-level system reduced flooding-related downtime by 40 % and increased production by 9 %.

Originality. The study proposes a differentiated design approach for mine access systems based on the morphological and hydrogeological characteristics of coal accumulation zones. The developed layouts provide an adaptive framework for managing high hydrostatic pressure and complex tectonic conditions in deep underground mining.

Practical value. The proposed solutions can be applied to other underground coal mines with similar geological settings in the Quang Ninh Basin, contributing to improved safety, enhanced resource recovery, and greater operational efficiency.

Keywords: *Nam Mau mine, Nam Khe Tam mine, coal accumulation zone, bottom of the zone, underground coal mining*

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Introduction. The Quang Ninh coal basin is the most important coal mining area in Vietnam, accounting for over 90 % of the country's underground coal production [1]. In the context of Vietnam's growing energy demand and its commitment to balancing economic growth with environmental sustainability, coal remains a crucial component of the national energy mix [2]. The Quang Ninh coal basin plays a vital role not only in energy security but also in regional socio-economic development [3]. However, as surface and shallow reserves are being depleted, mining activities have increasingly shifted toward deeper seams with more complex geological and hydrogeological conditions. These challenges require the development of new, adaptive, and safer mining technologies suitable for deep and structurally complex coal deposits, particularly those located at the bottom of the coal accumulation zone.

This coal region is located in the Northeast region, with a complex geological structure, characterized by large folds and faults, of which coal accumulation structures are common [4]. The coal accumulation areas are where valuable coal resources are concentrated, but their bottom, called the bottom of the coal accumulation zone, is an area with extremely complex geological and hydrological conditions, posing many risks in mining [5].

Safe and effective mining at the bottom of the coal accumulation zone has long been regarded as one of the greatest technical challenges for the underground coal mining industry in Quang Ninh [6].

In actual production at coal mines such as Nam Mau, Nam Khe Tam, Vang Danh and Ha Lam, the coal at the bottom of the coal accumulation zone is often unmined or only partially exploited due to serious risks. The main reasons are unstable geological conditions, the presence of complex fault systems, high groundwater pressure, weak mechanical properties of surrounding soil and rock, and high mine pressure. These factors increase the risk of water bursts, tunnel collapses, and underground structure deformation, causing labor safety hazards and significantly reducing the coal recovery factor. In particular, as the mining depth increases (many mines have gone below –300 m), dangerous factors become more evident, while increasing energy demand requires the thorough exploitation of resources [7].

Therefore, mining the bottom of the coal accumulation zone poses major technical challenges that need to be solved, including:

- establishing optimal technological processes for ventilation, drainage, and transportation;
- proposing a reasonable mine field division plan at the bottom of the coal accumulation zone (usually shaped like a basin or boat) to avoid coal loss;
- determining the optimal mining order to reduce the cost of tunnel protection and drainage costs for the area.

Many previous studies in Vietnam have focused mainly on coal seams with simple structures, without fully considering the complex geological and hydrologi-

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cal characteristics of the coal accumulation zone [8]. Although international nations have proposed several solutions, such as multi-level mine access, inclined shaft arrangements, stratified drainage systems, combined forced-natural ventilation, and ground support reinforcement using flexible materials, such as China [9, 10], Poland [11], Germany [12], Russian [13]. However, these methods cannot be directly applied to the Quang Ninh region due to the large differences in stratigraphy, mine pressure intensity, and technical infrastructure. Therefore, in-depth, localized research is needed.

On that basis, this study was conducted to propose reasonable and safe technical solutions for mining the coal at the bottom of the coal accumulation zone, ensuring economic-technical efficiency and mine safety. The two mines selected for the study are Nam Mau (complex structure, large slope angle, high groundwater pressure) and Nam Khe Tam (sloping seam, small coal accumulation, and shallow groundwater system), representing two common coal accumulation morphologies in the region, with the goal of developing a model applicable to other mines with similar conditions. Therefore, this study contributes both scientifically and practically to underground mining engineering in Vietnam. Scientifically, it develops a comprehensive framework for analyzing and designing safe and efficient mining systems under complex geological structures. Practically, it provides verified technological solutions applicable to deep underground coal mines in the Quang Ninh basin and other regions with similar geological settings. The research results serve as an important foundation for formulating future mining strategies aimed at enhancing resource recovery, ensuring operational safety, and promoting sustainable development in the coal industry.

Study area. The study area belongs to the underground coal mines in the Quang Ninh region, concentrated at Nam Mau and Nam Khe Tam mines, where there are many coal accumulations in the form of basins and boats. Nam Mau coal mine is located in Uong Bi city, Quang Ninh province, with coordinates approximately 21°01'–21°03' north latitude, 107°27'–107°29' east longitude. The mining area is on hilly terrain with relatively steep slopes and complex geology, making it suitable for underground coal mining. Currently, the mine operates at great depths using modern technologies on deep levels. The average elevation of the mining area is from 100 to 300 meters above sea level. This is a large coal mine, belonging to TKV Group, contributing greatly to coal output and revenue for Quang Ninh province. Nam Mau Coal Company has invested heavily in mechanized equipment, increasing labor productivity and improving working conditions. The mine is also associated with many social activities, supporting local community development. Nam Mau is a significant underground coal mine operating under the Vietnam National Coal and Mineral Industries Group (Vinacomin). Known for its thick coal seams, it is considered a major site for modern underground mining in Vietnam [14]. The mine has undergone continuous modernization with investments in mechanization and safety, aiming to increase labor productivity while ensuring worker safety.

In recent years, Nam Mau has expanded production capacity significantly, targeting annual outputs of over 1 million tons, and reaching 2.42 million tons in 2024. The company emphasizes environmental protection, investing in infrastructure to reduce the environmental impact of mining activities. The workforce is highly skilled, and the operation has been recognized for excellent safety records and production efficiency. Nam Mau also focuses on tech upgrades, including mechanized coal cutting and conveyor systems to improve operational efficiency and reduce labor intensity. The cross-section presented in Fig. 1 shows geological and hydrogeological complexities at the bottom of the Nam Mau accumulation zone. The figure visually confirms that the deep coal seams are characterized by significant burial depth and a highly complex tectonic structure. The coal seams exhibit a pronounced dip angle, and the entire structure is significantly fractured by multiple major and minor fault systems. These faults (marked in the figure) intersect the coal seams and surrounding rock, creating unstable zones. This figure illustrates the proximity of water-bearing strata (aquifers) to the main mining zone, particularly near the fault lines. These fractured zones

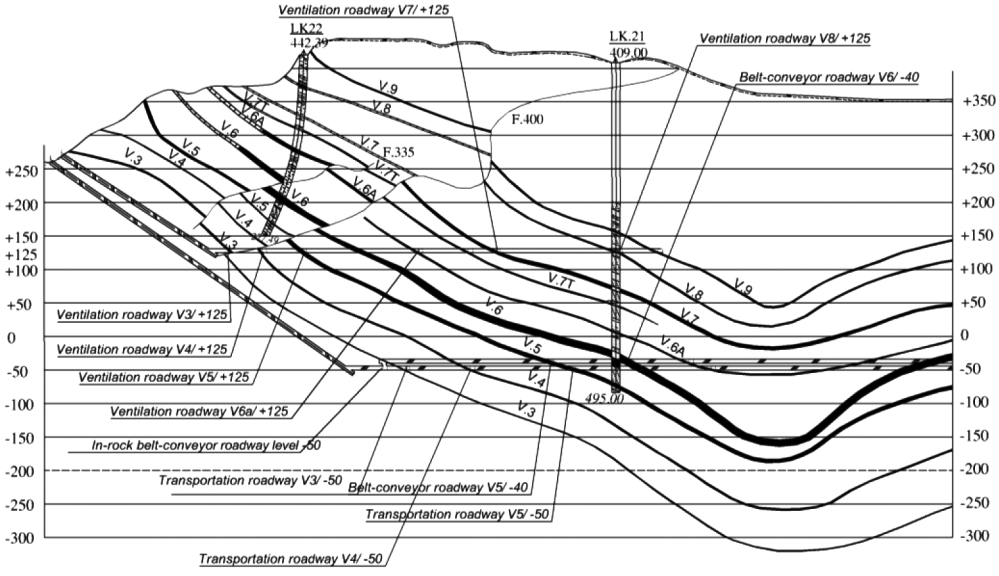

Fig. 1. Cross section of Nam Mau coal mine opening

act as high-permeability pathways, channeling large volumes of groundwater towards the mine bottom under extreme hydrostatic pressure. This complex structure and high-pressure hydrogeology severely restrict the available space for a safe single-level access system, underscoring the requirement for the dual-level system developed by this study to effectively manage water inflow and maintain stable access.

Nam Khe Tam Coal Mine is known mainly as Khe Tam Coal Mine and is currently exploited by Duong Huy Coal Company – TKV (Vietnam National Coal – Mineral Industries Group), headquartered in Cam Pha, Quang Ninh. The mine is located in an area with coordinates of about 21°01' north latitude, 107°25' east longitude. The mine is located in a low mountainous area, and the terrain is relatively flatter than Nam Mau, suitable for deep underground mining. The average slope of the mining area is from 15–30 degrees. The coal mine is mainly exploited at a depth of about –100 meters below ground level, with plans to expand the mining level deeper, and is implementing a plan to exploit below –100/–250 shafts. Khe Tam mine is a large underground coal mine with a designed capacity of 2.5 million tons/year, considered an important milestone in the sustainable development strategy of TKV, contributing greatly to the coal output of the Quang Ninh coal industry and playing a major role in the local economy [15]. There have been many investments in expansion and technological improvements to increase mining capacity. The mine plays an important role in local economic development, creating jobs and promoting socio-economic activities in the Cam Pha region. These mines are part of Vietnam's strategic coal production, featuring ongoing modernization and sustainable development efforts. The Nam Khe Tam mine, representing smaller accumulation zones, features moderately inclined seams at levels like –50 (Seam 9). Fig. 2 illustrates a characteristic single-level tunnel diagram for this zone, visually demonstrating the geometric constraints and the necessity of strategic central drainage required to manage localized water hazards in the moderately complex geological setting.

Methodology. The research data were collected from various sources, including geological-technical records, production reports, field measurement results, and experimental mining data. Geological and hydrogeological information was obtained from exploration drilling reports, geological structure maps, and groundwater level logs at the Nam Mau and Nam Khe Tam mines. These data were used to determine the morphology of the coal accumulation zones, aquifer depth, and fault distribution affecting mining safety.

Mining technical data included parameters of the roadway system, coal extraction methods, ventilation schemes, transportation routes, and drainage systems. These parameters were derived from official mine technical documentation and periodic reports of the Vietnam National Coal and Mineral Industries Group (TKV).

Experimental monitoring data were collected during the trial mining phase at the Nam Mau mine and comprised production output, coal recovery coefficient, mine gas pressure, drainage flow rate, and safety performance indicators.

In addition, ancillary data were obtained from mine design software, remote sensing imagery, and digital elevation models (DEM), which were used to simulate underground flow conditions and the morphology of the coal accumulation floor.

All data are standardized and integrated into a spatial database (GIS) for analysis, simulation, and multi-criteria evaluation. Data processing is performed using Surf-

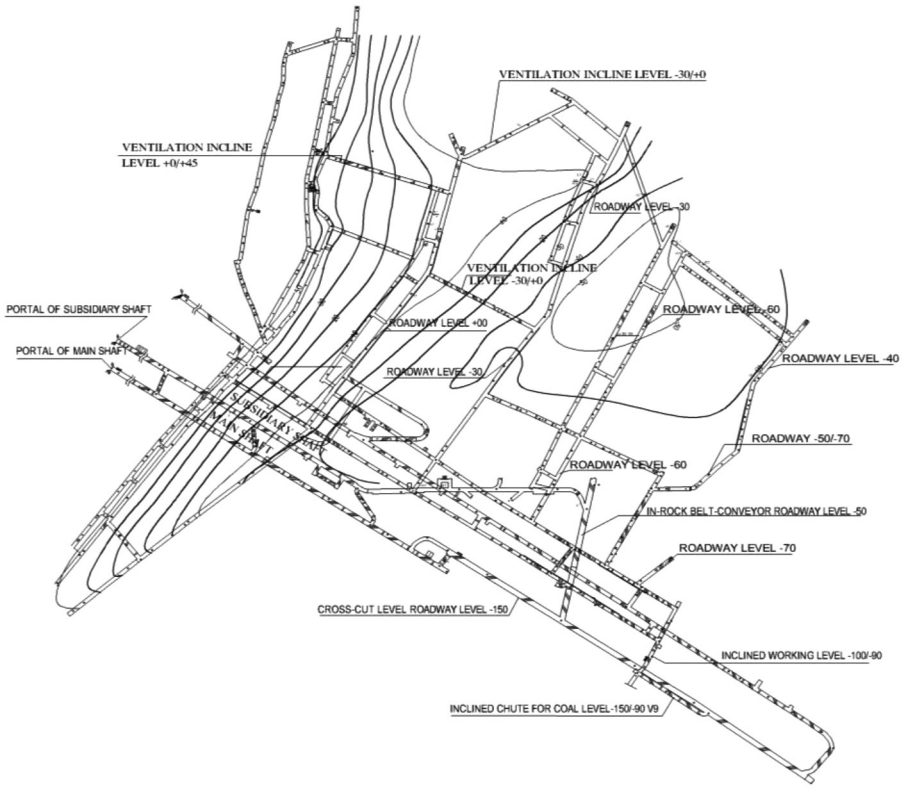

Fig. 2. Coal accumulation zone tunnel diagram of seam 9 at level –50 of Nam Khe Tam mine

er, ArcGIS, and Excel tools, ensuring consistency and high accuracy. The study was conducted based on the combination of theoretical analysis, field survey, technical simulation, and experimental evaluation, aiming to propose a suitable mining solution system for the bottom of the coal accumulation zone under the conditions of an underground mine in the Quang Ninh region.

The study employed a combination of theoretical analysis, field investigation, technical modeling, and practical validation to develop safe and efficient mining solutions for the bottom of the coal accumulation zone in underground coal mines of the Quang Ninh region.

Research data were collected from multiple sources, including geological-hydrogeological records, structural maps of coal accumulation zones, borehole logs, production reports, and field monitoring results at Nam Mau and Nam Khe Tam mines. Key datasets such as the morphology of the coal accumulation zone, coal seam inclination, mine pressure, groundwater conditions, and roadway systems were standardized and integrated into a spatial database (GIS). The data were processed and analyzed using specialized software such as Surfer, ArcGIS, AutoCAD Mine Design, and Excel to support multi-criteria assessment and 3D modeling of the bottom zones.

A systematic review of national and international studies was conducted to establish the theoretical framework concerning the geological structure of coal accumulation zones, underground mining systems, and hydrogeological control methods. The main technical parameters analyzed include seam inclination, rock mass mechanical properties, groundwater pressure, fold morphology, and ventilation capacity.

Empirical data from the study sites were statistically analyzed to establish representative geological and mining models. Advanced simulation tools (Rocscience, Surpac) were applied to model mining layouts, ventilation systems, and dewatering networks under complex geological and hydrogeological conditions. These models helped determine the optimal mining sequence, assess the stability of underground structures, and predict potential hazards such as water inrush, roof collapse, and roadway deformation.

A multidisciplinary expert method was used to verify and evaluate the feasibility of proposed solutions. Opinions from experts in mining engineering, geology, and mine safety (from the Vietnam National Coal and Mineral Industries Group – TKV and research institutes) were integrated to select the most technically sound and economically viable mining solutions for the bottom of the coal accumulation zone.

Pilot implementation was conducted at the Nam Mau Mine, focusing on the bottom area of Coal Seam 9 representative of complex hydrogeological conditions typical of Quang Ninh mines. Operational parameters such as production rate, coal recovery coefficient, groundwater inflow, ventilation flow rate, support stability, and operating costs were continuously monitored. These results provided the basis for assessing the technical-economic effectiveness and for refining the proposed technological schemes.

The final stage involved comparing the modeled and field-tested solutions in terms of recovery efficiency, safety performance, operating cost, and adaptability to other mines within the Quang Ninh coal basin. The outcomes were synthesized to propose an optimized mining technology and a systematic procedure for safe, efficient exploitation of coal seams at the bottom of the coal accumulation zone.

Results and discussion. ***Nam Mau mine.*** The study proposed a dual-level access plan for the coal accumulation zone of Seam 9, an area with large coal reserves but complex hydrogeological conditions. For bottom areas of the coal accumulation zone shaped elliptical, with a major axis longer than 250 m and minor axis longer than 200 m, the two-level mine opening plan is applied. In this method, the upper part of the bottom is accessed by a cross-seam tunnel, and the bottom is opened by raises excavated from the cross-seam tunnel of the lower level. This opening method facilitates ventilation and drainage at the bottom of the coal accumulation zone and minimizes coal loss due to fewer support pillars left for the opening tunnels. Fig. 3 presents the detailed Dual-Level Access Layout specifically developed for the bottom of the deep and tectonically complex Seam 6A accumulation zone at the Nam Mau mine. This plan is the central technical response to the severe geological and hydrogeological challenges identified in Fig. 1.

The layout is characterized by the strategic division of the mine bottom into two distinct, interconnected sub-levels (e.g., an upper and a lower sub-level). The lower sub-level is designated primarily as the main drainage and pumping infrastructure, effectively isolating the high-water-risk zone from the primary production level above it. This separation is vital for continuous operation and minimizes the risk of catastrophic water inrush due to the high hydrostatic pressure. The dual-level system facilitates a clear division of operational tasks. The upper level focuses on coal extraction and transport, while the lower level ensures efficient ventilation return and water collection. This spatial arrangement enhances air circulation efficiency and provides stable, non-congested access routes, dramatically improving overall operational safety and productivity in the confined, deep-seated working area:

- lower level (–250) digging a tunnel through the seam to drain water and arrange the main transport route;
- upper level (–175) arranging an upper rock furnace for ventilation and gas release.

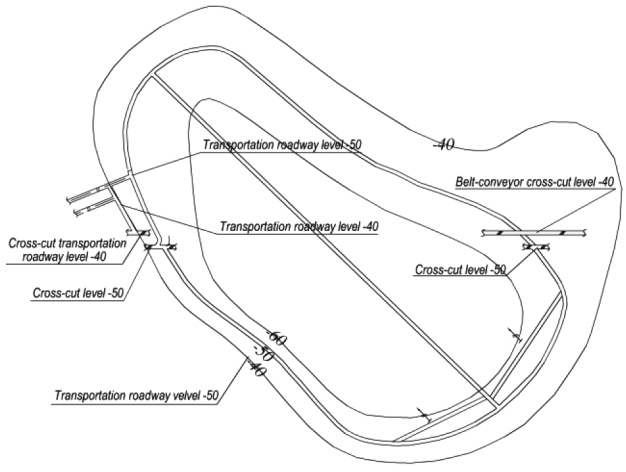

Fig. 3. Division plan for the bottom of the coal accumulation zone seam 6A at Nam Mau coal mine

The two levels were connected by an inclined shaft designed to regulate the wind and lead self-flowing water to the concentration pit. This solution reduced water accumulation by 35 %, increased the ventilation efficiency by 1.45 times, and stabilized mine pressure, without water bursting during the testing process.

The selected mining system was along-strike longwall panel division, with coal extraction carried out by controlled drilling and blasting, and roof support provided by ZH-1600/16/24 hydraulic shield supports. The operational results indicated:

1. Average productivity: 400–420 tons/day.

2. Coal recovery coefficient: 0.90 (compared to 0.82 previously).

3. Drainage costs reduced: 12–15 %;

4. Total mine output increased by: 8–10 %;

5. No accidents due to water bursts or collapses.

Nam Khe Tam mine. Due to the smaller scale of the coal accumulation zone (axis length < 200 m), the authors applied a single-level access system combined with an inclined panel mining layout. Fig. 4 serves to further validate the application of the Single-Level Access System for smaller-scale accumulation zones, similar to the setting illustrated in Fig. 2, but at the higher Level +60 of the Nam Khe Tam mine (Seam 11).

This diagram confirms the system's adaptability: Despite the difference in elevation and seam number, the fundamental principle remains the same: accessing the reserve from a single main level with sub-galleries driven towards the boundary. This demonstrates the schematic's inherent flexibility to adjust to minor geological variations within the same mine. Unlike the central drainage focus in Figs. 2, 4 layout emphasizes the positioning of the main access and ventilation ways relative to the seam's boundary. This design ensures that the working face maintains a high concentration of air circulation and a minimized haulage distance from the extraction point to the main tunnel. This simplified, single-level design, successfully applied at both levels –50 (Fig. 2) and +60 (Fig. 4), proves its cost-effectiveness and operational efficiency for exploiting reserves in moderately complex structures where the dual-level complexity is not warranted.

The main cross-seam furnace is located at the level –150, which acts as both a transport and a main drainage channel. Auxiliary raises were connected to the upper mining levels to provide natural ventilation.

The drainage system adopted a combined model of self-flowing and forced pumping, using vertical pumps with a capacity of $Q = 30$ m^3/h and a head of $H = 120$ m. After implementation, water accumulation decreased by 40 %, production downtime due to flooding was reduced by 45 %, and mining productivity increased by 9 %. The mining system utilized single hydraulic props (2×250 kN), suitable for moderately inclined seams, ensuring high stability and ease of movement. The technical and economic performance was recorded as follows:

- coal recovery coefficient: 0.88 (increased by 6 % compared to the old method);

- reduction in transportation and drainage costs (10 %);

- air humidity in the furnace is stable at 83–85 %, meeting mine safety standards.

Comparison and evaluation of the overall effectiveness. The results of comparing the two mines are shown in Table 1. The comparative results presented in this Table reveal clear differences in the technical behavior and operational efficiency between the two representative mines. The dual-level access system applied at Nam Mau Mine proved to be more effective in areas with high groundwater pressure and steep coal seams (30–70°). The two-level layout, consisting of separate drainage and ventilation horizons, enhanced hydraulic control, reduced water accumulation by approximately 35 %,

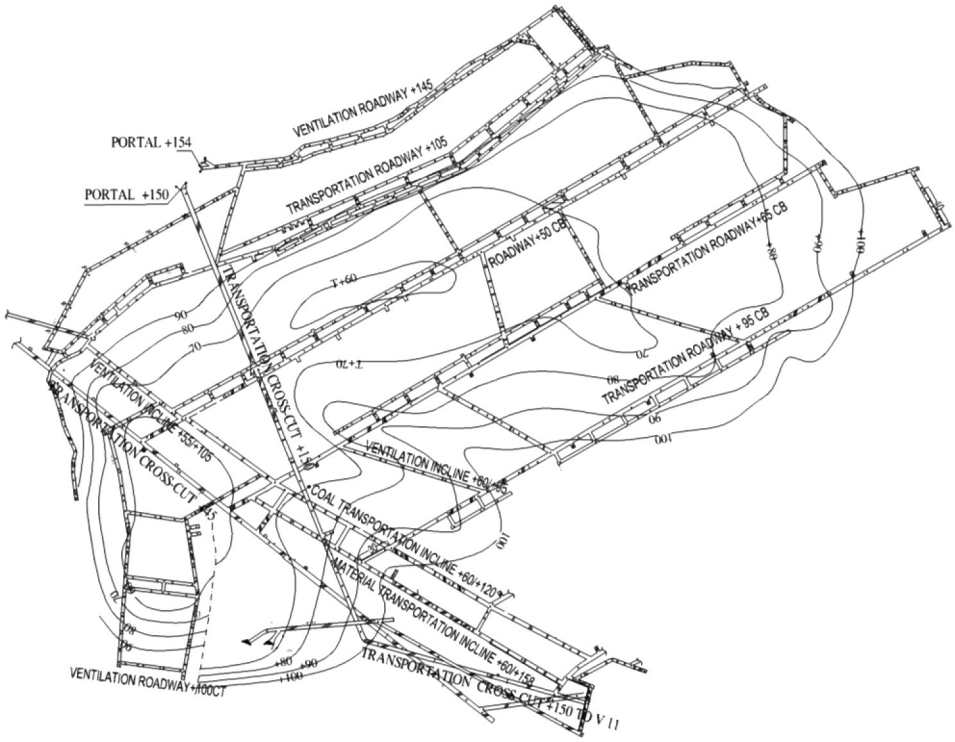

Fig. 4. Coal accumulation zone tunnel diagram of seam 11 at level +60 Nam Khe Tam mine

and increased ventilation efficiency by 1.45 times compared to the previous single-level configuration. These improvements not only stabilized mine pressure but also eliminated the risk of water inrush during production. As a result, the recovery factor at Nam Mau reached 0.90, while drainage costs decreased by 12–15 %, demonstrating high technical and economic efficiency under complex hydrogeological conditions.

In contrast, the single-level access system implemented at Nam Khe Tam Mine was more suitable for gently inclined seams (20–45°) and smaller coal accumulation zones where the groundwater inflow is moderate. This simpler configuration reduced construction costs and facilitated natural ventilation. Despite its less complex layout, the system effectively reduced flooding downtime by 40–45 %, increased productivity by 9 %, and maintained a coal recovery factor of 0.88, while ensuring workplace stability and safety. The use of vertical pumps (Q = 30 m^3/h, H = 120 m) and single hydraulic props (2 × 250 kN) further optimized drainage and structural support efficiency.

Overall, the analysis of Table 1 demonstrates that the dual-level access method at Nam Mau Mine is technically superior for deeper and high-pressure zones, whereas the single-level system at Nam Khe Tam Mine offers greater cost-effectiveness and adaptability to moderate geological conditions. Both models ensure operational safety, stability, and significant economic gains by improving resource recovery and reducing production interruptions. The proposed mining systems fully meet the technical, safety, and economic requirements for coal extraction at the bottom of the coal accumulation zone, and their successful implementation at Nam Mau and Nam Khe Tam confirms their feasibility and scalability for other underground coal mines in the Quang Ninh basin. These results provide a robust practical foundation for developing a standardized technological framework for mining in coal accumulation zones, contributing to maximized resource utilization and reduced coal losses across the region.

Assessment of practicality and economic and technical efficiency. The research results have contributed to strengthening the theoretical foundation for mining in areas with complex coal accumulation structures, where geological, hydrogeological, and geomechanical factors interact closely. The proposed solutions were not solely based on traditional geological and mining theories but also incorporated three-dimensional technical modeling to determine stress fields, groundwater distribution, and mine gas migration patterns. The development of a dual-level access system for large coal accumulation zones and a flexible single-level system for smaller ones represents a novel approach, allowing the mining system to be adaptively designed according to the morphological characteristics of each mine.

Table 1

Results of comparing the two mines

Criteria	Nam Mau mine	Nam Khe Tam mine
Type of mine opening	Dual-level	Single-level
Seam dip angle	30–70°	20–45°
Groundwater discharge (m^3/h)	8–25	5–15
Increase in coal recovery factor, %	+8	+6
Reduced mine drainage cost, %	12–15	10
Increase in productivity, %	8–10	9
Reduced mining downtime, %	40	45

In addition, the study proposed a longwall mining system divided along the strike, combined with a mobile frame and single hydraulic support, ensuring flexible load-bearing capacity, reduced roadway sidewall deformation, and maintained roof stability under high mine pressure conditions. This solution replaces traditional support methods (such as timber or discrete metal props), thereby enhancing safety and increasing mining productivity by 8–10 %.

The experimental results at Nam Mau and Nam Khe Tam mines demonstrated that the proposed models achieved high technical and economic efficiency.

At Nam Mau mine, the dual-level access system reduced water accumulation by 35 %, achieved a coal recovery factor of 0.90, and lowered drainage costs by 15 %. At Nam Khe Tam mine, the flexible single-level approach reduced production downtime due to flooding by 40 % and increased average productivity by 9 %.

A notable advantage is the integration of forced-natural ventilation and gravity–pumping drainage, which reduced energy consumption, minimized water inrush incidents, and maintained a safer working environment. These results indicate that the proposed solutions can be applied stably and sustainably, with strong potential for replication in other Quang Ninh mines with similar geological structures, such as Ha Lam, Vang Danh, and Khe Cham.

Compared with traditional methods, the coal seams at the bottom of the coal accumulation zone are often left unmined or extracted manually due to complex hydrogeological conditions and high mine pressure. The single-level mining methods combined with wooden or simple bolt supports cannot ensure safety when encountering large groundwater flows. Compared with those methods, the solution proposed in this study offers several outstanding advantages as follows:

- to reduce the risk of water bursting and the collapse of the furnace thanks to the arrangement of two mining opening levels;
- to increase the stability of underground structures through the use of advanced support systems;
- to optimize costs and improve the coal recovery factor, enabling the extraction of previously "neglected" resources at the bottom of the coal accumulation zone.

Limitations and future research directions. Although the results are very promising, the study still has some limitations. The simulation models have only been tested at two representative mines (Nam Mau and Nam Khe Tam), and therefore do not fully cover the complex geological and hydrogeological conditions of the entire Quang Ninh coal basin. In addition, mine pressure and groundwater flow parameters are strongly influenced by seasonal variations and mining activities in adjacent levels, which should be monitored using Hydro-Geomechanical modeling in future research. Moreover, the current study has not yet incorporated dynamic coupling between hydrogeological changes and stress redistribution during long-term operations. The applied numerical models primarily reflect static conditions, while actual mining processes are influenced by continuous

deformation, gas migration, and groundwater fluctuations. Future studies should therefore integrate time-dependent hydro-geomechanical simulation to capture these dynamic behaviors more accurately. Another limitation lies in the monitoring and control systems, which remain largely manual. To enhance operational safety and predictive capacity, future research should focus on developing IoT-based sensing networks, AI-assisted early warning systems, and automated control of ventilation and drainage operations. These technologies will facilitate real-time decision-making and risk mitigation, especially in deep mining environments with complex tectonic coal accumulation zones.

Future research should focus on advancing the technical and scientific foundations of underground coal mining in complex geological environments. Priority should be given to applying three-dimensional numerical models that integrate geological, hydraulic, and geomechanical factors, enabling a more accurate representation of the interactions among rock stress, groundwater flow, and structural deformation under real mining conditions. Further development of time-dependent hydro-geomechanical simulations will allow researchers to capture dynamic changes in pressure and water migration during continuous operations. In parallel, the implementation of IoT-based monitoring networks and AI-assisted early warning systems will facilitate real-time data acquisition and automated control of ventilation, pumping, and mine pressure, thereby improving both safety and operational efficiency. To validate these technologies, it is necessary to expand field experiments to deeper syncline structures (> 400 m) in order to assess long-term stability and adaptability under higher stress and water pressure conditions. From a sustainability perspective, future studies should also examine the energy efficiency and environmental performance of the proposed mining systems, focusing on optimizing drainage energy use, recycling mine water, and reducing carbon emissions. Integrating these technological and environmental innovations will drive the transition toward smart, sustainable, and resilient underground coal mining in Vietnam's deep and tectonic coal accumulation zones, ensuring both resource efficiency and long-term safety in the coal industry.

In summary, the proposed technical solutions are not only feasible under the specific conditions of the Nam Mau and Nam Khe Tam mines but also hold strategic significance for Vietnam's underground coal mining industry, contributing to more efficient resource utilization, reduced geological risks, and enhanced long-term safety for mine workers.

Conclusion. This research applied an integrated approach combining theoretical analysis, 3D modeling, and field validation to propose innovative mining solutions for the bottom of coal accumulation zones in the Quang Ninh coal basin. The methodology included geological and hydrogeological surveys, simulation-based stability assessment, and expert evaluation to optimize mine layout, drainage, and ventilation systems.

The dual-level access method developed for Nam Mau Mine and the single-level system for Nam Khe Tam Mine both demonstrated high technical reliability and operational safety. The proposed schemes achieved significant improvements in performance: water accumulation decreased by up to 40 %, mine pressure remained stable, the coal recovery factor reached 0.88–0.90, and drainage costs were reduced by 10–15 %. These advances contribute to the safe exploitation of previously unmined reserves at the bottom of the coal accumulation zone, improving overall mining efficiency and reducing geological risk.

In terms of application, the proposed solutions are suitable for underground coal mines with similar geological structures across the Quang Ninh region, such as Ha Lam, Vang Danh, and Khe Cham. Their implementation can enhance production stability, increase resource recovery, and ensure long-term operational safety. Looking ahead, future research should focus on integrating hydro–geomechanical simulation, real-time monitoring systems, and smart mine technologies including AI-based prediction and IoT-driven ventilation and drainage control to develop an intelligent, adaptive management framework for deep underground coal mining in Vietnam.

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Технічні рішення для безпечного й ефективного видобування вугілля у глибоко розташованих зонах накопичення у басейні Куанг-Нін (В'єтнам)

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Мета. Розробка та апробація технічних рішень для безпечного й ефективного видобутку вугілля в нижніх частинах глибоких зон накопичення, що характеризуються складними геологічними й гідрогеологічними умовами. У ході дослідження розглядаються такі ключові проблеми як високий тиск підземних вод, розломні структури та знижена стійкість гірничих порід, на прикладі підземних шахт Нам Мау та Нам Кхе Там, що виступають типовими об'єктами дослідження.

Методика. Методологія дослідження поєднувала аналіз геологічно-гідрогеологічних даних, створення просторової бази даних, тривимірне чисельне моделювання, експертну оцінку й пілотну перевірку в польових умовах. На основі структурних і гідрогеологічних характеристик були розроблені та впроваджені дві системи розкриття та підготовки: дворівнева схема розкриття для великих і глибоких зон вугленакопичення (шахта Нам Мау) й оптимізована однорівнева схема розкриття для менших і помірно нахилених пластів (шахта Нам Кхе Там).

Результати. Практичне впровадження підтвердило технічну ефективність запропонованих систем. На шахті Нам Мау дворівнева схема дозволила зменшити накопичення ґрунтових вод на 35 %, підвищити ефективність вентиляції в 1,45 раза й повністю усунути випадки затоплення під час випробувального періоду. На шахті Нам Кхе Там оптимізована однорівнева система дозволила скоротити простої, пов'язані із затопленням, на 40 % і збільшити видобуток на 9 %.

Наукова новизна. У дослідженні запропоновано диференційований підхід до проєктування систем доступу до шахт, що ґрунтується на морфологічних і гідрогеологічних характеристиках зон вугленакопичення Розроблені схеми забезпечують адаптивну основу для управління високим гідростатичним тиском у складних тектонічних умовах глибокого підземного видобування.

Практична значимість. Запропоновані рішення можуть бути застосовані на інших підземних вугільних шахтах із подібними геологічними умовами в басейні Куангнінь, що сприятиме підвищенню безпеки, збільшенню видобутку корисних копалин і підвищенню ефективності експлуатації.

Ключові слова: *шахта Нам Мау, шахта Нам Кхе Там, зона вугленакопичення, придонна частина, підземний видобуток вугілля*