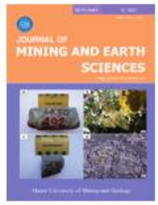
Journal of Mining and Earth Sciences, Vol 64, Issue 6 (2023) 23 - 31

Journal of Mining and Earth Sciences

Website: http://jmes.humg.edu.vn



Mineralogical and geological characteristics and potential of iron resources in Tan An area, Yen Bai province

Khang Quang Luong [1,*], Hung The Khuong [1], Quang Van Le [2]

[1] *Hanoi University of Mining and Geology, Hanoi, Vietnam*
[2] *Radioactive and Rare Minerals Division, Hanoi, Vietnam*

ARTICLE INFO

Article history:
Received 03rd Aug. 2023
Revised 03rd Nov. 2023
Accepted 28th Nov. 2023

Keywords:
Characteristics,
Iron resources,
Mineralogical and geological,
Potential,
Tan An area.

ABSTRACT

The Tan An area in Yen Bai province, located in northwestern Vietnam, is known for its high potential for iron deposits. The region has several iron occurrences, including Tan An, Nghia Hung, Buu Village, and Tran Phu Farm. The authors conducted a comprehensive study of the region using various geological and mineralogical analysis techniques to better understand the iron mineralization process. Their findings indicate that iron mineralization in the area is the result of metamorphic and hydrothermal processes characteristic of magnetite-quartzite and hematite types. The iron content in the orebodies varies from medium to high values, with an average range of 27.5÷63.7%. These results provide valuable insight into the prospect of iron resources in the Tan An region, serving as a foundation for identifying the most promising areas for further exploration. To estimate the iron resources in the study area, the Huvo method was used, yielding a total estimated amount of 11.4 million tons of Fe-metal, including 2,028,026 tons in the Tran Phu Farm area, 360,611 tons in the Buu Village area, 426,534 tons in the Nghia Hung area and 8,605,065 tons in the Tan An area at iron resource level 334a. These findings provide a preliminary assessment of the potential iron resources in the area. The study's results are significant, providing valuable information for future iron exploration and development activities in the Tan An region. With this knowledge, mining companies and investors can make informed decisions about the feasibility of mining iron in the area. Additionally, the study's results may lead to the creation of new jobs in the mining industry, benefiting the local economy and the region as a whole.

*Corresponding author
E - mail: luongquangkhang@humg.edu.vn
DOI: 10.46326/JMES.2023.64(6).03

1. Introduction

Iron is an important element for life with a wide range of applications in human health, industry, and the environment. It is widely used in the production of steel, machinery, tools, and household appliances due to its magnetic properties. Iron also plays a crucial role in the growth and development of crops and the cycling of nutrients in soil and water. However, excess iron can be harmful, causing damage to organs and promoting the growth of harmful bacteria. Overall, iron plays a crucial role in various aspects of the world, from human health and industry to the environment. It is essential to maintain a balance of iron intake to ensure its benefits without causing harm.

Mineral resource estimation holds significant practical importance in mineral investigation, as emphasized by previous studies (Zhang & Huang, 2010; Kuzvart & Böhmer, 1986; Hung et al., 2020; Hung and Dung, 2021; Hung and Cong, 2021; Hung and Tri, 2021; Khang and Hung, 2022). It provides a scientific and practical foundation for organizing geological survey programs and assessing mineral and investment opportunities. For decades, researchers have investigated and proposed various methods for estimating mineral resources during geologic mapping and surveying procedures. Mineral resource assessments often rely on geological mapping and mineral prospecting conducted on a scale ranging from 1:200,000÷1:50,000. Recently, numerous geological and statistical approaches have been developed for estimating mineral resources. Among these, similarity-analogy in ore geology and mineral resource estimation based on Huvo methods have been widely adopted to investigate mineral resources (Byryukov, 1962; Zhang & Huang, 2010; Hung et al., 2020; Hung and Dung, 2021; Hung and Cong, 2021). Various estimation methods have been employed for different scenarios depending on factors such as ore boundaries, geological geometry, grade variability, and available time and resources. To choose appropriate methods for a research object, the stage of geological investigation, the completeness of the document, the geological structure characteristics of the object, and the mineral type should be carefully investigated. Northwestern Vietnam is a location with abundant iron resources (Tri and Khuc, 2011). However, the mineral resource estimation methods used so far have relied on qualitative descriptions and rigid formulas and parameters, making them unsuitable for the mineral market's variability. Therefore, it is essential to calculate and estimate the iron resources and reserves in the Tan An region, not just for scientific purposes but also to establish the exploitation orientation and processing to ensure the rational use of mineral resources. A model for evaluating iron resources based on various boundary content options should be studied to have a more comprehensive and flexible view of mineral resource estimation in this area. As such, northwestern Vietnam is an ideal location to apply this asymptotic approach to estimating iron resources.

It is proposed that the Huvo method is suitable for describing and estimating iron resources. Based on the Huvo method, this paper aims to work out the formulae of the relationships between iron tonnage and iron contents. The Tan An area, in northwestern Vietnam, is selected as a case study.

2. Geological settings

The Tan An area is located within a region that is distinguished by the presence of diverse metamorphic rocks, including amphibolites that are part of Archean the Suoi Chieng complex, Proterozoic the Sin Quyen formation and late Cambrian - early Ordovician fine-grained greenstones of the Ben Khe formation (Vinh, 1972; Binh, 2013).

The Suoi Chieng complex (AR*sc*) is comprised of quartz-biotite schist, quartz-feldspar-mica schist, and amphibolite interlayered with quartzite-magnetite. This stratigraphic level includes magnetite-quartzite, which is regarded as a precursor to the exploration target of iron-bearing quartzite within the same group of sheets and other areas that share similar geological characteristics.

The Sin Quyen formation ($PPsq$) is dominated by quartz-biotite schist, quartz-feldspar schist, quartz-mica-garnet schist, and fine-grained quartzite interlayered with either quartz vein rock or amphibolite.

The Ben Khe formation (ϵ_2-O_1bk) is distributed in the northeast of the ore deposit area and stretches over a length of more than 7km in the northwest-southeast direction. Its lithology is characterized by sericite-chlorite schist intercalated with quartzite and veined limestone. Furthermore, the valleys within the mining area accumulate gravel, pebbles, sand, and multi-component clay of the early Cretaceous age without differentiation.

In the mining area, the newly intruded magma complexes have only revealed small granitoid and gabbro-amphibolite bodies, including the Xom Giau complex (PP_1xg). This complex is identified in an area where alkaline granite intrusions with sizes ranging from several tens to several hundred square meters were observed, intersecting the metamorphic rocks of the Suoi Chieng formation containing magnetite-quartzite. The Xom Giau complex is a complex intrusive magmatic system that has complicated or destroyed iron ore bodies. The Bao Ha complex (PP_3bh) has only recently been discovered with a few small intrusions (several tens of square meters) intersecting the Xom Giau alkaline granite complex and iron ore veins. This magmatic intrusion has complicated the structural region and destroyed iron ore bodies in the area.

The study area is characterized by a northwest-southeast trending fault system that controls the ore deposit and a northeast-southwest trending strike-slip fault system that complicates the iron ore bodies. However, at the intersections of these fault systems or in areas where fractures are concentrated, creating a breccia zone, there are favorable traps for the formation of hydrothermal iron ore veins, as observed in the Tran Phu Farm and Nghia Hung village.

3. Materials and methodologies

This investigation was conducted through the implementation of geological surveying and mapping techniques, utilizing the 1:50,000 scale Geological and Mineral Resources Map of Vietnam for the Van Chan map sheet group (Vinh, 1972; Binh, 2013). In the Tan An region, a total of 36 chemical samples, 30 thin section samples, and 10 block section samples were gathered by the Northern Geological Mapping Division to conduct chemical, mineralogical, and petrographic analyses. Surface and drilling methodologies, including openings and core samples, were employed to explore the mineralization zones. The mineralized zone of category 334 resources in the Tan An area was analyzed through the examination of geological features and the application of level research within the investigated region. In addition, ore geology similarity-analogy and Huvo methods were implemented to estimate the mineral resource.

3.1. Chemical analysis of the composition of ores

To facilitate research on the material composition of rocks, ores, altered rock zones, geological features, and the behavior of gold in geological processes and their origins, the applied methods have been categorized into the following groups.

This group comprises methods used to analyze the chemical composition of rocks and ores, including fusion, atomic absorption spectroscopy, plasma spectroscopy, silicate chemistry, and ICP-MS.

The group includes methods for analyzing the mineral composition of rocks and ores, including crushing, mineralogy, thin section, and SEM, which are used to determine the symbiotic mineral combinations of ores as well as the generation of minerals in rocks and ores.

The group of methods involves processing data using specialized computer software.

3.2. Ore resource estimation method

The Huvo method applied to predict iron ore resources for newly explored ore bodies in the preliminary study phase is assigned a corresponding resource category of 334a. The predicted iron ore resource P (in tons) is determined using the following formula.

$$P = V \times d \times C \qquad (1)$$

Where: d - density of the ore body (T/m^3); C - metal iron content (%); and V - volume of the ore body (m^3).

The formula for determining the volume V is as follows.

$$V = L \times H \times M \tag{2}$$

Where: L - length of the mineralization zone or ore body is determined on a map (m); H - depth of the existence of the mineralization zone or ore body (m); M - average thickness of the ore body (m).

The depth of existence of the ore body is determined by the method of rectangular extrapolation.

$$H = \frac{1}{4}L \tag{3}$$

4. Results and Discussion

4.1. Characteristics of the iron orebodies distribution

The research area has been divided into four distinct zones based on their iron ore deposits. These zones are known as Tan An, Buu Village, Nghia Hung, and Tran Phu Farm. Each of these zones is characterized by a unique composition of iron ore deposits, which vary in terms of their quality and quantity. The identification and mapping of these zones can provide valuable insights into the distribution and potential of iron ore resources in the area.

In the Tan An area, iron ore is formed from metamorphic sources, comprising 12 ore bodies (from TQ.16÷TQ.27) distributed in the north of the Tho stream (Figure 1, Table 1).

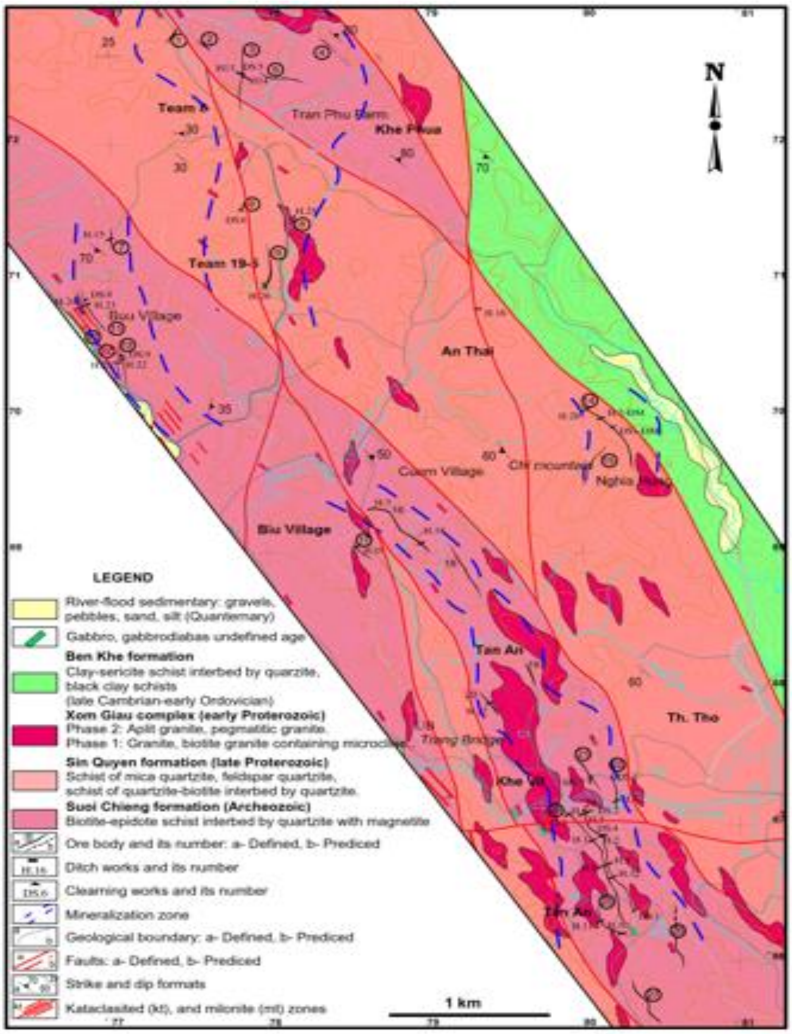


Figure 1. Simplified geological map of the Tan An area, showing the location of the iron mineralization zone (adapted from Vinh, 1972; Binh, 2013).

These ore bodies are characterized as quartzite-magnetite veins, varying in length from 150÷1000 m and in thickness from 0.6÷28 m. They are found in parallel and joint with surrounding rock layers in the NW-SE structural direction. The iron ore is made up of a band that varies from indistinct to distinct in black-brown color with strong magnetism. The total iron (Fe) content varies from 24.37%÷36.28%; manganese (Mn) content varies from a small amount to 0.08; and sulfur (S) content is low. Typical characteristics of the iron ore bodies are presented below.

Iron ore body TQ.16 includes 350 m in length, with an average thickness of ~1 m, controlled by the H.18-TA and VC.989 works. The ore body consists of quartzite-magnetite veins lying in parallel with the surrounding rock layers. The ore is composed of a band with an indistinct shape, black-brown color, and strong magnetism, with a total Fe content of 35.72% and Mn content of 0.01%.

Iron ore body TQ.22 is 250 m long and has an average thickness of 0.6 m. It is controlled by the H.4-TA, H.3-TA, and DS.7 works and consists of quartzite-magnetite veins lying parallel to the surrounding rock layers. The ore has an indistinct shape, black-brown color, and strong magnetism. Its total Fe content is 33.04% and its Mn content is 0.05%.

Iron ore body TQ.23 is 900 m long with an average thickness of 15 m and is controlled by the H.7-TA, H.1-TA, and H.9-TA works. The ore body consists of quartzite-magnetite veins lying in parallel with the surrounding rock layers. The ore has a basilisk-shaped band with a black-brown color and strong magnetism and it has an average total Fe content of 29.92% and a low Mn content. Iron ore body TQ.24 has a length of over 1000 m, an average thickness of 18m, and is controlled by the H.2-TA, H.5-TA, H.6-TA, H.8-TA, H.12-TA, DS.1 and DS.4 works. The ore body is oriented in a NE-SW direction with the veins dipping to the NW at an angle of 60÷70^0. The ore is composed of an indistinctly shaped band with a black-brown color and strong magnetism. Its average total Fe content is 33.71% and the Mn content ranges from 0.01÷0.08%.

The iron ore deposits in the Buu Village area are of metamorphic origin and comprise five ore bodies (designated as TQ.7 and TQ.10 through TQ.13) (Figure 2, Table 1). These ore bodies consist of thick quartzite-magnetite veins that range in thickness from 0.8÷5 m and in length from 200÷350 m. Their trends are in a northeast-southwest direction. The quartzite-magnetite veins dipping to the northwest usually have dip angles ranging from 60÷80^0 and are conformably interbedded with the surrounding rocks. The ore bodies have a ribbon-like to distinct shape, are black-brown, strongly magnetic and contain a total Fe content (%) ranging from 20.84÷38.07.

Figure 2. The iron ore body TQ.11 is observed at the VC.848 outcrop in the Buu Village (after Binh, 2013).

The Tran Phu Farm area contains two distinct types of iron ore deposits with different origins. The first type is hydrothermal-origin iron ore and consists of ore bodies TQ.2, TQ.3, TQ.6, TQ.8, and TQ.9. The second type is metamorphic-origin iron ore and comprises ore bodies TQ.1, TQ.4 and TQ.5 (Table 1).

4.2. Iron ore and non-metallic minerals

The analysis of mineral samples from the iron ore deposit in the Tan An area indicates that the mineral composition is relatively uncomplicated. The primary ore minerals present are magnetite, pyrite, and hematite, with lesser amounts of limonite and chalcopyrite. The non-ore minerals identified are primarily quartz and biotite.

The dominant ore mineral in the sample is magnetite, accounting for 55÷60% of the

Table 1. Characteristics of iron ore bodies in Tan An area, Yen Bai.

Area	Ore body	Length (m)	Thickness (m)	Depth (m)	Content (%)
Tran Phu Farm	TQ.1	200	0.8	50.0	30.00
	TQ.2	100	10.0	25.0	30.00
	TQ.3	450	11.0	112.5	47.40
	TQ.4	300	0.1	75.0	30.00
	TQ.5	300	1.5	75.0	30.00
	TQ.6	100	0.3	25.0	30.00
	TQ.8	80	1.0	20.0	63.70
	TQ.9	300	11.0	75.0	39.20
Buu Village	TQ.7	200	2.0	50.0	32.44
	TQ.10	300	3.0	75.0	38.70
	TQ.11	350	3.0	87.5	28.70
	TQ.12	250	2.0	62.5	34.05
	TQ.13	300	3.5	75.0	27.50
Nghia Hung	TQ.14	560	1.5	140.0	58.70
	TQ.15	350	1.0	84.0	52.25
Tan An	TQ.16	350	1.0	87.5	35.72
	TQ.17	200	0.6	50.0	32.52
	TQ.18	350	1.0	87.5	32.52
	TQ.19	150	1.0	37.5	32.52
	TQ.20	150	1.5	37.5	34.98
	TQ.21	300	1.0	75.0	31.59
	TQ.22	250	0.6	62.5	33.04
	TQ.23	900	15.0	225.0	29.00
	TQ.24	1000	18.0	250.0	33.20
	TQ.25	350	1.0	37.5	32.52
	TQ.26	650	3.0	62.5	30.14
	TQ.27	200	1.5	50.0	32.52

composition. These minerals exhibit equilateral square, hexagonal, and tetragonal shapes, with some appearing as irregular, elongated structures. The distribution of magnetite is uniform and oriented within non-metallic minerals. Hematite is relatively scarce in the sample and is a secondary product formed through the alteration of magnetite during the martitization process. Hematite has a flaky structure, with small particles forming a network that grows from the cracks in magnetite or replaces it in the form of rims or bands. Pyrite is present in low concentrations, ranging from trace amounts to 2%, and is sparsely distributed within the non-metallic minerals, typically exhibiting a rectangular shape. Chalcopyrite is the least abundant mineral, accounting for 1% or less. It has an irregular, protruding shape with a uniform distribution in the mineral rock matrix (Figure 3).

The primary constituents of the sample are non-ore minerals, such as quartz and biotite. Biotite, in particular, contains predominantly ore minerals, primarily magnetite.

The non-metallic and altered rock mineral group includes quartz, feldspar, and mica. Quartz is the most abundant mineral, most of which is strongly fractured and oriented along the compression direction. Some remaining quartz grains have larger sizes (0.3x0.6 mm). The majority of the quartz grains are compressed and display wave extinction. Quartz below 1 Nicol is colorless with moderate birefringence and those below 2 nicols display bright white first-order interference color. In thick sections, they exhibit first-order interference color in shades of green and red. Feldspar is present in small amounts in the sample and most of the crystals are secondarily altered or heavily corroded, with a size of less than 0.01 mm. Mica is also present in small amounts in the sample, mainly biotite, with small flakes elongated along the cleavage direction and intercalated between quartz grains or along the vein margins. Most of the mica flakes are secondarily altered into chlorite.

4.3. Iron ore resources potential

The obtained results suggest that the total iron metal resources in the Tan An area amount to approximately 11.4 million tons of Fe (Table 2). This includes 2,028,026 tons in the Tran Phu Farm area, 360,611 tons in the Buu Village area, 426,534 tons in the Nghia Hung area and 8,605,065 tons in the Tan An area at resource category of 334a.

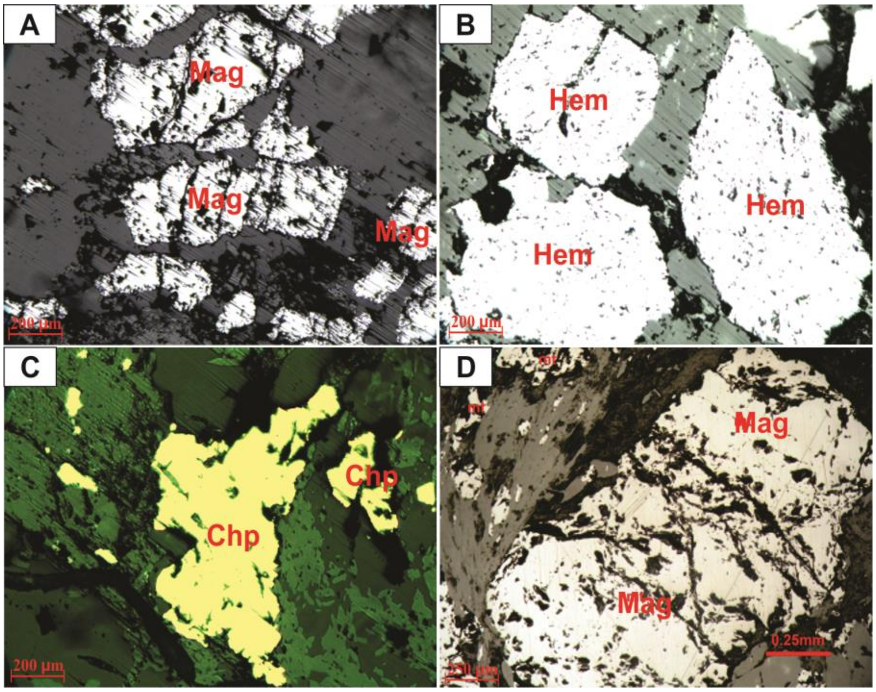


Figure 3. Several images of the ore mineralization association in the Tan An area (photos taken by Quang Van Le). A, D - Magnetite occurs as irregular, elongated structures. B - Hematite occurs as a flaky structure, with small particles forming a network that grows from the cracks in magnetite or replaces it in the form of rims or bands. C - Chalcopyrite occurs in an irregular, protruding shape with a uniform distribution in the mineral rock matrix. Mag: Magnetite, Hem: Hematite, Chp: Chalcopyrite.

Table 2. Results of the predicted iron resources for Tan An area, Yen Bai province.

Area	Ore body	Volume (m^3)	Density (T/m^3)	Content (%)	Iron resources in 334a category (tons)
Tran Phu Farm	TQ.1	8,000	3.5	30.00	8,400
	TQ.2	25,000	3.5	30.00	26,250
	TQ.3	556,875	5.4	47.40	1,425,377
	TQ.4	2,250	3.5	30.00	2,363
	TQ.5	33,750	3.5	30.00	35,438
	TQ.6	750	3.5	30.00	788
	TQ.8	1,600	5.4	63.70	5,504
	TQ.9	247,500	5.4	39.20	523,908
	Total				2,028,026
Buu Village	TQ.7	20,000	3.5	32.44	22,708
	TQ.10	67,500	3.5	38.70	91,429

	TQ.11	91,875	3.5	28.70	92,288
	TQ.12	31,250	3.5	34.05	37,242
	TQ.13	78,750	5.4	27.50	116,944
	Total				360,611
Nghia Hung	TQ.14	117,600	5.4	58.70	372,768
	TQ.15	29,400	3.5	52.25	53,765
	Total				426,534
Tan An	TQ.16	30,625	3.5	35.72	38,287
	TQ.17	6,000	3.5	32.52	6,829
	TQ.18	30,625	3.5	32.52	34,857
	TQ.19	5,625	3.5	32.52	6,402
	TQ.20	8,438	3.5	34.98	10,330
	TQ.21	22,500	3.5	31.59	24,877
	TQ.22	9,375	3.5	33.04	10,841
	TQ.23	3,037,500	3.5	29.00	3,083,063
	TQ.24	4,500,000	3.5	33.20	5,229,000
	TQ.25	13,125	3.5	32.52	14,939
	TQ.26	121,875	3.5	30.14	128,566
	TQ.27	15,000	3.5	32.52	17,073
	Total				8,605,065
Total iron resources in the whole area					11,420,236

The research findings indicate that the Tan An area in Yen Bai province, northwestern Vietnam, has greater potential for iron ore compared to the Van Chan region. This discovery has important implications for provincial management agencies in the planning and exploitation of iron ore in the area. By taking into account the potential for iron ore in Tan An, provincial authorities can develop more effective strategies for resource allocation, environmental management, and economic development in the region.

5. Conclusion

The synthesis and analysis of literature, supplement and related samples in the Tan An area of Yen Bai province lead to the following conclusions.

The iron ore in the Tan An area is located in a complex geological structure of folds and faults. The iron mineralization is distributed across 04 mineralized zones, with the Tran Phu Farm having 08 ore bodies, the Buu Village comprising 05 ore bodies, the Nghia Hung including 02 ore bodies and the Tan An obtaining 12 ore bodies.

The iron content in the ore bodies in the Tan An area varies unevenly, with a significant difference between the lowest and highest contents. The study's results on the chemical composition and mineralization stages allow the classification of iron ore in the area into magnetite quartzite and hematite types.

The research results show that the Tan An area has considerable potential for primary iron ore, with an estimated total resource of approximately 11.4 million tons of Fe. In general, Tan An is an area with potential for iron ore both on the surface and at depth. Therefore, a comprehensive investment strategy is needed to evaluate the potential of iron ore in the area.

Acknowledgments

The paper was written to commemorate the 45th anniversary of the Prospecting and Exploration Geology Department, which has been a cradle for training many geologists who have made significant contributions to the construction and development of the nation.

Contribution of authors

Khang Quang Luong – Conception, design of the study, and drafting of the manuscript, analysis and/or interpretation of data; Hung The Khuong - Conception, design of the study, and draft the manuscript, acquisition of data, analysis and/or interpretation of data; Quang Van Le - Acquisition of data, analysis and/or interpretation of data.

References

Binh, P. T. (ed.) (2013). Report on geological mapping and mineral investigation of the Van Chan, Yen Bai sheet group at 1:50,000 scale. The Vietnam Geological Department (in Vietnamese).

Byryukov, V. I. (1962). Classification of exploration systems of solid mineral deposits. *Geology of Ore Deposits 1*, *Moscow*, 99–121 (in Russian).

Hung, K. T., Cong, N. T. (2021). Mineralogical geochemical characteristics and resource potential of copper ore in the Lang Chanh area, Thanh Hoa Province. *Science & Technology Development Journal – Natural Sciences, 5*(4), 1651-1662 (in Vietnamese). https://doi.org /10.32508/stdjns.v5i4. 1092.

Hung, K. T., Dung, H. T. (2021). Mineralogical - geochemical characteristics of gold mineralization and its potential in the Tuong Duong area, Nghe An province. *Journal of Mining and Earth Sciences, 62*(3b), 30-40 (in Vietnamese). https://doi.org/10.46326 /JMES.2021.62 (3b).04.

Hung, K. T., Sang, P. N., Phuong, N., Dung, N. T., Bac, B. H., Phi, N. Q., Sang, B. V. (2020). Polymetallic Nodules Resource Estimation in the Suoi Thau-Sang Than Area, Northeastern Vietnam. *Inżynieria Mineralna - Journal of the Polish Mineral Engineering Society*, *46*(2), 7-14. https://doi.org/10.29227/IM-2020-02-03.

Hung, K. T., Tri, L. D. (2021). Hydrothermal and Metasomatic Kaolin Resource Estimation in the Quang Ninh area, northeastern Vietnam. *Iraqi Geological Journal*, *54*(2E), 176-185. https://doi.org/10.46717/igj.54.2E.12Ms-2021-11-28.

Khang, L. Q., Hung, K. T. (2022). Talc resources potential in the Pa Long-Bo Xinh area, Son La province. *Mining Industry Journal*, No 1-2022, 73-77 (in Vietnamese).

Kuzvart, M., & Böhmer, M. (1986). *Prospecting and exploration of mineral deposits*. Volume 21, 2nd Edition, Elsevier, Technology & Engineering, 508 pp.

Tri, T. V., Khuc, V. (eds.) (2011). Geology and Earth Resources of Vietnam. General Department of Geology and Minerals of Vietnam. Publishing House for Science and Technology, 645 pp.

Vinh, N. (ed.) (1972). Report on geological and mineral resources of the Yen Bai area at 1:200,000 scale. The Vietnam Geological Department (in Vietnamese).

Zhang, Z., Huang, W. (2010). Evaluation Method on Geological Deposit Potential Value. *International Journal of Business and Management, 5*(6), 210–214.