



## Mineral Resources Potential of Vietnam and Current State of Mining Activity

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### Abstract

Vietnam, with an area of 331,210 km<sup>2</sup>, occupies the eastern side of the Indochina peninsula. It forms a narrow (locally only 40-70 km) band of land, extending over 1,500 km along the East Sea (South China Sea).

Vietnam is constituted mainly by the folded belts surrounding two shields, cratonised in the Upper Proterozoic: the Yangtze craton and the Indochina shield, located in the Mekong basin and occupying most of Cambodia and the contiguous parts of Laos and Vietnam. The folding occurred during the late Hercynian (early Triassic) orogenic movements, active mainly in the central and southern Vietnam and the Indosinian (late Triassic, ante Norian) orogeny.

Various geological surveys have indicated that Vietnam is well endowed with a wide range of mineral resources. The country has some of the world's biggest resources of phosphate (apatite), bauxites, rare earths, and large, commercially viable deposits of oil, coal, gold, gemstones, copper, zinc, tin, chromite, manganese, titanium (mineral sands), graphite and other minerals.

At present, Vietnam produces approximately 3.5 million tons of crude oil/year and its mineral production includes: coal (about 10.7 million tons a<sup>-1</sup>), cement (1.6 million tons), phosphate (300,000 tons), chromite (3.5 million tons), iron ores, gold (around 1,000 kg, including production by the local population), cassiterite (3,000 tons), graphite, kaolin and many other minerals produced to serve domestic demand. Several foreign companies are involved in oil exploration (BP, Total, BHP) as well as in prospecting (seldom in exploitation) for minerals (mainly Australian companies).

In spite of the current mineral production, the country's mining sector is still underdeveloped and many available mineral resources remain unexploited. Nevertheless, this situation is changing. The recent but increasing level of involvement of foreign companies in the Vietnamese mineral sector will accelerate the development of high value and/or export-orientated minerals, especially as some of the neighboring countries (China, Japan, South Korea ...) lack many mineral resources. And the developing Vietnamese economy will surely entail mining of various minerals for the domestic use.

**Keywords:** Mineral resources; Vietnam; Metallic; Nonmetallic; Energy; Actual state; Mining

### Introduction

Vietnam has been endowed with a diversified geology and rich Earth resources though its area is not so large. On the territory of Vietnam, including its mainland, seas and islands, geological formations and Earth

resources have arisen from countless geological events, over billions of years.

Research into Vietnam's geology was first conducted by French geologists at the end of the nineteenth century. From 1945 onwards, especially since 1954, studies and basic surveys on the geology and mineral resources of Vietnam have been carried out by Vietnam geoscientists from the former General Department of Geology under the Ministry of Industry, now the General Department of Geology and Minerals of Vietnam under the Ministry of Natural Resources and Environment, as well as geoscientists at the Ministry of Sciences and Technology, the Ministry of Education and Training, the Vietnamese Academy of Sciences and Technology, the Vietnam National Oil and Gas Group (Petro-Vietnam), the Vietnam Coal and Minerals Industries Group (VINACOMIN), the Vietnam National Committee for IGCP and the Vietnam Union of Geological Sciences, among others. These include geological mapping and mineral surveys at different scales from 1:1,000,000 to 1:50,000, thematic studies exploration and reserve assessments, with accumulation of many valuable data, with the help of geologists from the former Soviet Union, China and East-European countries in the early stage and more recently, in collaboration with geologists from France, Japan, the Republic of Korea and other countries. In the meantime, surveys, prospecting, exploration and exploitation of Earth resources have been extended to the entire country, creating the basis for the development of many new types of mineral, energy and groundwater resources, significantly contributing to national development.

The territory of Vietnam is situated in the central part of Southeast Asia, belonging to the Eurasian lithosphere plate, which has a geological development history from Archeozoic to present with a rich geological endowment and diversified geo-resources. Thousands of mineral occurrences have been discovered and hundreds of them have been subjected to evaluation. Especially, from prospecting and exploration the resources of many mineral, energy and groundwater resources have been evaluated, many of them are being exploited, such as oil and gas, coal, phosphate, ilmenite,

chromite, cassiterite, construction materials, kaolin, silica sand, pyrophyllite, baryte, lead-zinc, copper, gold, fluorite, etc. as well as thermal and mineral waters.

### **Brief outline of geology of Vietnam**

#### *1) Tectonic settings*

Vietnam and neighboring countries have an amalgamation structure from different terranes which have accreted and collided with each other in different orogenic epochs. The Indosinia, Hoang Lien Son and Hoang Sa (Paracel) Precambrian continental blocks form micro continents.

Extended between them as composite terranes there are the Sino-Vietnamese Fold Belt consolidated in Early-Middle Paleozoic, Viet-Laos Fold Belt consolidated in Middle-Late Paleozoic, and Indochina Fold Belt consolidated in Early Mesozoic (Figure 1).

The Mesozoic superimposed depressions form intracontinental rifts, namely: Song Da, Song Hien, An Chau, Sam Nua, An Khe and Tu Le Rifts, as well as grabens, namely: Hon Gai, Nong Son Grabens, and Da Lat Volcano plutonic Margin. The Cenozoic superimposed depression created lacustrine and fluvial depressions in the mainland, and deltaic, coastal depositional basins on the continental shelf of Vietnam, that have potentiality in petroleum. The East Vietnam Marginal Sea appeared from the extension of the sea floor, and the Tay Nguyen Basalt Aureole was formed by the extrusion tectonism [1-3].

#### *2) Stratigraphy*

The migmatized crystalline schists of granulite facies belonging to *Archean*, and of amphibolites facies belonging to *Proterozoic* are exposed on the Kon Tum Block in central Vietnam, and on the Hoang Lien Son Block in north Vietnam. The Phanerozoic sedimentary and volcano-sedimentary rocks have been differentiated into *Neoproterozoic-Lower Cambrian* groups or formations dated mainly by acritarchs, *Cambrian-Lower Ordovician*, *Ordovician-Lower Silurian*, and *Upper Silurian* formations dated mainly by trilobite and graptolites, Devonian formations by coelenterates and brachiopods, sometimes, fishes, Carboniferous-

Permian formations by forams and rugoses, plant remains, Lower-Middle Jurassic groups and formations which are of red continental facies in the north dated mainly by sporomorphs, and marine facies or marine grading upward to red continental facies in the south by ammonites, bivalves and silicified wood, Upper Jurassic Cretaceous volcanogenic formations by isotopic elements, and Cretaceous red continental formations, by spores and pollens, Tertiary formations by forams, molluses, plant remains, spores and pollens, and at last, Quaternary sediment of different genetics dated mainly by forams, moll uses, spores and pollens, and C<sup>14</sup> method.

### 3) Magmatism

Igneous intrusive and effusive rocks have been discriminated into different complexes, the activities of which took place in 7 main stages: Archeozoic, with metagabbro and granitoid complexes; Paleo-Mesoproterozoic and Neoproterozoic-Early Paleozoic, with associations of basalt-diabase, gabbro amphi-bolite, tonalite-plagiogranite and alkaline granite; Early-Middle Paleozoic and Late Paleozoic-Early Mesozoic with associations of basalt-diabase, dunite-peridotite pyroxenite, andesite-rhyolite, granodiorite-granite, syenite, and in some places of north and central Vietnam-basalt-rhyolite, granite-granophyres, Late Mesozoic-Cenozoic with associations of andesitobasalt, rhyolitedacite and alkaline rocks which are widespread in south central Vietnam and west of north Vietnam; Late Cenozoic with mainly of tholeiitic basalt and olivine basalt on the plateau of south central Vietnam.

### Mineral resource potentiality of Vietnam

The systematic materials on mineral resources have been showing that there exist many kinds of mineral resources on the territory of Vietnam, which have been passing through investigations and explorations of different levels (Figure 2). They are composed of rare ea mineral groups of iron and ferrous alloys, base metals, light metals, rare earths, precious metals, energy, raw materials for chemical and fertilizer industry, for porcelain, glass, heat-insulated and refractory substance production construction materials, technical raw materials,

Triassic formations by ammonoids, bivalves and precious and semi-precious stones, mineral and thermal waters [3-7].



**Figure 1** Tectonic map of Vietnam: 1. Cenozoic troughs; 2. Mesozoic troughs; 3. Area of Indosinian folding (Lower Triassic); 4. Area of Late hercynian folding (Lower Triassic); 5. Kontum Massif; 6. Trap' basalts; 7. Granite massifs; 8. Proterosoic; 9. Faults.

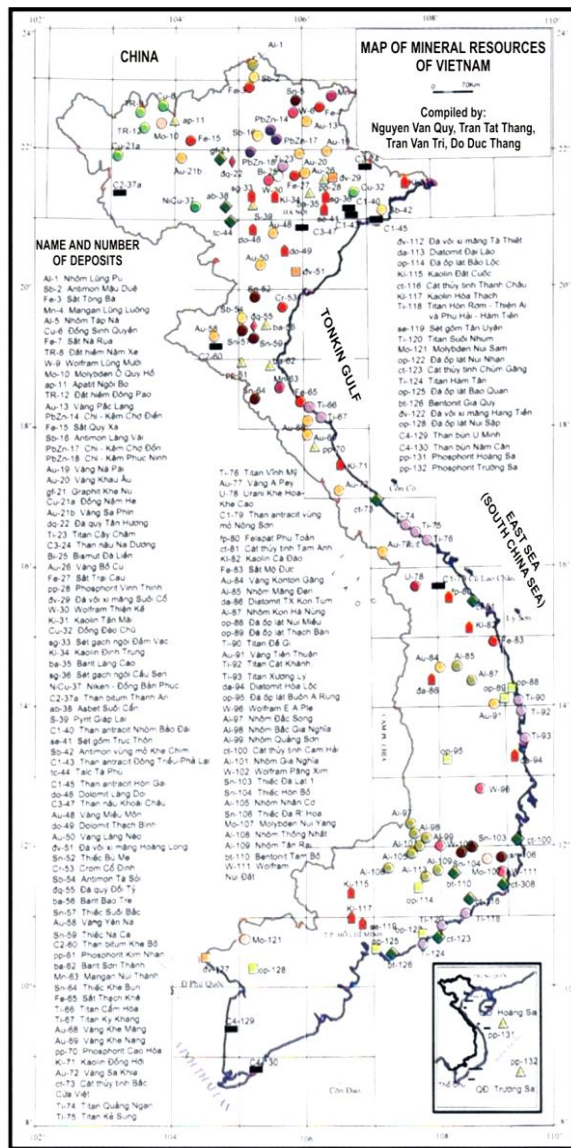


Figure 2 Map of mineral resources of Vietnam.

## 1) Metallic minerals

### 1.1) Iron and ferroalloy metals

Iron is distributed in many places in Vietnam with hundreds of deposits and occurrences of different genetic types, among them those of skarn and weathering geneses are of greater value. Ores of skarn genesis occupy large resources in the total known resources of iron ores, although the quantity of these deposits is not numerous. The most valuable deposit of this genetic type is the Thach Khe deposit, the resources of which (554 million tons, Fe > 60%) occupy the most part of the total resource of about 600 million tons of iron ores. Ores of weathering deposits have commercial value. In these deposits, iron ores are composed of 3 kinds: limonite, brown iron ore and iron-

manganese ore, with the total resource of 185 million tons of iron ores (50% Fe).

Manganese has been recognized with 34 deposits and occurrences, but the most part of industrial ore is concentrated in the NW part of the Cao Bang Province. Ore in this area is of sedimentary genesis of Late Devonian age, with the resource of over 12-13 million tons. Manganese ores at Chiem Hoa (Tuyen Quang Province) originate from weathering and precipitation in Lower Devonian sediments, with the resource approximating 170,000 tons.

Chromium at present has been reported only in the Codinh chromite placer mine and the ones surrounding it in Thanh Hoa Province, with an indicated resources of about 22 million tons of chromite. Apart from chromium, nickel and cobalt have also been reported.

Titanium (ilmenite) and zircon ilmenite occurs in 66 deposits and occurrences, both primary and placer. The former are found in gabbroic Nui Chua massif, situated northwest of Thai Nguyen. It consists of layered ilmenite dissemination (30-70% FeTiO<sub>3</sub>) at the base of the gabbro. The proven resources are 2.8 million tons. Vietnam's potential in marine placers is considerable. Mineral sands containing ilmenite, subordinate zircon and some monazite and xenotime, are known at many places along the country's coastline, stretching over some 1,500 km. About 50 major and medium-sized occurrences have been delineated with the total resource estimated at nearly 15 million tons of ilmenite.

### 1.2) Base metals

Copper has been recognized in tens of deposits and occurrences of magmatic, hydrothermal, and sedimentary (copper-bearing sandstone) geneses, located in three main areas, namely: Lao Cai, Son La and Bac Giang. Ores of magmatic genesis have been found in deposits in Ta Khoa and Van Yen areas, where the nickel content is double that of copper. The most valuable ores of hydrothermal genesis have been known in the Sinh Quyen deposit, Lao Cai Province, with the resource of 551,000 tons of copper, 334,000 tons of rare earths (RE<sub>2</sub>O<sub>3</sub>) and 35 tons of gold. The ores of sedimentary genesis have been known in Triassic sandstone in Bac Giang Province on a small scale.

Lead-zinc are fairly widespread in North Vietnam, with nearly 400 deposits and occurrences, over 50 of which have been investigated. They are of hydrothermal, skarn and weathering geneses; of them the skarn type, found in carbonate-terrigenous formations distributed in many places in north Vietnam is the most important, with its well known Cho Don and Cho Dien mines. The resource amounts to nearly 1 million tons of lead-zinc, among which that of the Phia Khao and Cho Dien mines occupies nearly 80%.

Nickel and cobalt have magmatic, hydrothermal and weathering geneses. Those of magmatic genesis are related to ultramafic intrusions at Son La, Cao Bang and Thai Nguyen Provinces. The Ban Phuc deposit (Ta Khoa area) has a resource of about 193,000 tons of nickel-copper, among it, 119,000 tons of nickel and nearly 3,500 tons of cobalt. Nickel and cobalt ores still exist in the Co Dinh chromite placer mine with the Ni content of 0.51-0.64%; and Co: 0.05-0.12%, with the hypothetical resource of about 3 million tons of nickel and over 271,000 tons of cobalt. Apart from these, cobalt and nickel have been found in the Sinh Quyen copper deposit.

Aluminum (bauxite) in Vietnam has been found in 2 sedimentary and weathering geneses. The sedimentary bauxite, of late Permian age, is concentrated in Ha Giang, Cao Bang, Lang Son, Hai Duong and Nghe An Provinces with the total resource of nearly 200 million tons of  $Al_2O_3$ . The bauxite located in the weathering crust of Neogene-Quaternary basalt is concentrated mainly in south Vietnam with a total resource of laterite bauxite of 6.75 billion tons.

Tin is known in over 100 deposits and ore occurrences of pegmatite, skarn, hydrothermal and placer geneses. Only the ores of hydrothermal genesis are payable. They are represented by the cassiterite-silicate-sulphide ore formation found in Tam Dao, Quy Hop, Quang Nam and Lam Dong areas, with a resource of nearly 130,000 tons of cassiterite. The placer tin ore is the object of the tin exploitation industry in the above-cited mines during some recent decades. The resource reaches over 135,000 tons of cassiterite.

Bismuth in Vietnam has been usually found in tin, lead-zinc and tungsten deposits of hydrothermal and skarn geneses. The scheelite-bismuth mineralization of skarn genesis has been known

only in Da Lien mine, Thai Nguyen Province, with the  $WO_3$  content: 0.13-0.26%; Bi: 0.1-0.22%; and the  $WO_3$  resource of over 160,000 tons, the bismuth resource of over 140,000 tons.

Tungsten is of hydrothermal origin, with the quartz-wolframite-cassiterite type related Cretaceous-Paleogene granites, distributed in West Thai Nguyen, Cao Bang, Thanh Hoa, Quang Nam, etc. areas, with a resource of over 100,000 tons of  $WO_3$ . Those of skarn origin bearing scheelite and bismuth have been known only in the Da Lien deposit with low  $WO_3$  content (0.132-0.264%), but the re-source may reach over 170,000 tons.

Molybdenum has been recognized in 40 deposits and ore occurrences, located in 2 main areas, namely: Sa Pa (Lao Cai Province) and Nui Sam (An Giang Province). They have hydrothermal origin, with a resource of over 45,000 tons of molybdenum.

Antimony and mercury have been found in nearly 50 deposits and occurrences of hydrothermal genesis with the antimony-gold mineralization type, distributed in many places of North Vietnam, among them the Lang Vai deposit, Tuyen Quang Province has an antimony resource of 98,000 tons and arsenic resource of 200,000 tons. True antimony has been known in the Khe Chim deposit, Quang Ninh Province with the antimony resource of 35,000 tons, the Mau Due deposit, Ha Giang Province with the antimony resource of 60,000 tons. The antimony-mercury ores have been found in Bàn Cam and Yen Ve. Mercury ores are fairly widely distributed across North Vietnam.

### 1.3) *Precious and rare metals, rare earth elements*

Gold has two genetic types: placer and hydrothermal. Placer gold is distributed in many places. Up to now, about 150 gold placers have been discovered in all corners of the country. As for hydrothermal gold, it is widely distributed, including various mineralization types, such as: quartz-gold in Thai Nguyen and Thanh Hoa Provinces, quartz-gold-tourmalin in Phu Tho Province, quartz-gold-sulphide in many places, gold-silver in central Vietnam, gold-antimony in Tuyen Quang and Quang Binh Provinces, and paragenetic gold in polymetal ores, such as lead-zinc, pyrite, chalcopyrite in the Sinh Quyen

deposit. The total resource of gold reaches some thousands of tons, among which the inferred reserve has been evaluated as some hundreds of tons.

Platinum has been known at present in the platinoid group located in ultramafic intrusive rocks, that accompanies copper-nickel mineralizations of the Ban Phuc mine, and possibly of the Nui Nua mine area.

Silver usually accompanies other ores in the deposits of zinc, copper, cobalt, nickel, and tin. The hypothetical resource of silver is of account, and ranges at about 20,000 tons.

Rare earths (RE). Besides rare earths contained in monazite and zircon in the mineral sands, Vietnam has large deposits of RE in carbonatites, discovered in the late 1950s and located in the Fan Si Pan Mts., in the north of the country. Three deposits were delineated: Nam Xe North and South and Dong Pao. At Nam Xe, tabular or lens form ore bodies are hosted in the permo-carboniferous limestones. The mineralization is complex, consisting of bastnaesite, parisite, uranopyrochlore, gadolinite, pyrite, apatite and abundant baryte and fluorite. The weathered zone, to a depth of 20 m, contains 4-5% of RE oxides and the primary ore is averaging 1.4% REO (mainly Ce, La, Nd, Pr, Y, but also Gd and Eu - 4% of REO), 1,1% Nb, 200-300 ppm U and 30% Ba. The reserves are huge; 7.8 million tons of REO, of which 1.7 million tons are proved at Nam Xe North alone. Dong Pao deposit, situated 40 km S has about 7 million tons REO of a similar quality. It is hosted in a paleogenesyenitic intrusion (53 Ma).

## 2) *Non-metallic minerals*

### 2.1) *Gemstones*

Rubies and sapphires of gem quality are found in different areas, such as Luc Yen, Tan Huong, Truc Lau (Yen Bai Province), Qui Chau-Quy Hop (Nghe An Province), Dak Ton (Dak Nong Province), Ma Lam, Da Ban (Binh Thuan Province), etc. Many other gemstones have been also discovered, including spinel, tourmaline, quartz, aquamarine, garnet, topaz, zircon, peridot, opal-chalcedony and petrified wood.

### 2.2) *Industrial minerals*

Apatite (phosphate) has been found in Lower Cambrian metamorphic rocks at Lao Cai. The

phosphate ores have been classified into 4 grades, among them grades I and III consist of weathering (secondary) ores which were naturally beneficiated giving soft and loose ore, the II and IV grades consist of primary carbonate-phosphate ores lying under the weathering zone. The ores of the II and IV grades have the hypothetical resource to the depth of -900 m reaching 4 billion tons. The total resource of all the 4 ore grades of the Lao Cai phosphate basin reaches over 5 billion tons, in which the demonstrated reserves are 90 million tons.

Phosphorite has been found in many places in the form of precipitation in karstic caves in limestone, but its resource is of small scale. The guano phosphorite precipitated from bird excrement in low islands has been found in many islands of the Paracel (Hoang Sa) and Spratly (Truong Sa) archipelagoes.

Baryte ores of hydrothermal genesis are the most valuable in Vietnam. They have been found in 21 deposits and occurrences together with lead-zinc or with rare earths. The total resource of baryte reaches about 25 million tons, among it the resource of Dong Pao deposit occupies 4 million tons.

Fluorite has only been investigated in 4 deposits of hydrothermal genesis with following geneses: fluorite-baryte-rare earths found in the Dong Pao deposit with the resource of over 10 million tons of fluorite; fluorite-quartz with the resource of about 270,000 tons of fluorite; fluorite-tin-wolfram with the resource of only about 20,000 tons of fluorite.

Pyrite has been so far discovered, investigated and explored in over 100 deposits and occurrences in Bac Bo and Trung Bo with the total resource of 46 million tons of S. This ore has two genetic types: hydrothermal metasomatic and hydrothermal effusive, both found in West Bac Bo.

Serpentine formed by the alteration of ultramafic intrusive rocks has been found in Thanh Hoa and Yen Bai Provinces. Its chemical composition meets the requirement of the flux used in the production of baked phosphorous fertilizer. The resource reaches about 15 million tons.

Peat has been investigated in over 100 deposits and occurrences of Holocene age.

They belong to 4 types, such as: intermontane plain, plain in low mountain zone, alluvial plain, and coastal plain. The two U Minh Thuong and U Minh Ha deposit has the resource of about 426 million m<sup>3</sup>, occupying over 75% of the total peat resource of the whole country.

Porcelain clay is distributed in Miocene and Quaternary formations, or formed in the weathering crust of gabbro massifs, or of terrigenous sediments. The total resource (29 mines, deposits and occurrences) reaches about 220 million tons.

Dolomite exists in 2 types: primary sediments distributed in carbonate formations aged from Devonian to Triassic; and metamorphic sediments distributed in formations aged from Proterozoic to Early Paleozoic. The total resource of 16 investigated deposits reaches nearly 985 million tons.

Feldspar has been investigated in 7 deposits with the total resource of nearly 24 million tons. They belong to 2 types: feldspar in granite pegmatite, having high quality; feldspar in other magmatic rocks, such as quartz keratophyre, felsite, and aplite.

Kaolin is very abundant, with a scattered distribution in many places with 136 investigated mines, deposits and occurrences and a total resource of 1,993 million tons. They have been classified into 3 genetic types. The weathering type includes the weathering crust of pegmatite bodies, of felsic intrusive massifs and effusive bodies, and of terrigenous sediments, with identified resources of 30 million tons. The redeposited type includes Quaternary sediments formed in intermontane valleys, river terraces, and coast terraces with the identified resources of nearly 60 million tons. The hydrothermal metasomatic type includes kaolin pyrophyllite bodies in Middle Triassic felsic effusive of Tan Mai area (Quang Ninh Province), with identified resources of over 57 million tons.

Silica sand has been found in Quaternary formations of following genetic types: deluvial-proluvial, alluvial bank, and marine eolian types. Over 40 deposits have been investigated and explored. Especially, silica sand is largely distributed along the seashore and around islands from Quang Ninh to Kien Giang Provinces with the resource of over 1.27 million tons.

Refractory clay has been investigated in 9 deposits with the total resource approximating 120 million tons. It is of following origins: Upper Pleistocene sediments, Neogene sediments, Upper Triassic coal-bearing formation, and weathering crust.

Diatomite has been known mainly in middle central Vietnam. It is distributed in Neogene at Lam Dong and Phu Yen Provinces with the resource approximating 140 million cubic metres, and in Kon Tum Province with the resource of 171 million cubic metres.

Graphite is composed of following genetic types: Precambrian sedimentary metamorphic hydrothermal pneumatolytic, distributed along the left side of the Red River, such as in Lao Cai, Yen Bai, and in Middle Trung Bo, such as Quang Ngai, Lower Paleozoic hydrothermal pneumatolytic found only in Tuyen Quang, Thai Nguyen, Thanh Hoa and Quang Nam Provinces. The total identified resources reach 13.5 million tons, and the resource is estimated at 6 million tons.

Talc of hydrothermal genesis belongs to the following types: altered dolomite in carbonate-rich formation in the middle Da river basin with the resource of over 246,000 tons; altered ultramafic and mafic rock bodies which are distributed along the Song Ma Zone.

Asbestos has been found in 24 deposits and occurrences which are closely related to ultramafic and mafic magmatic massifs with small concentrating scale.

Muscovite has found in granite pegmatite bodies distributed in Proterozoic metamorphic formations of Lao Cai, Phu Tho and Quang Nam Provinces, among them the deposits at Lao Cai has inferred resource of primary muscovite of 1,358 tons and of separated muscovite of 558 tons.

Vermiculite has been preliminarily investigated, and found only in 5 deposits in Phu Tho, Son La, and Lai Chau Provinces, among them the deposits in Phu Tho have been investigated, giving the resource of 29,000 tons.

Bentonite has been found so far in 25 deposits, among them 15 have been investigated, and only 2 explored and exploited. It is distributed in Neogene and Quaternary formations, as well as in the weathering crust of the Thuan Hai dry zone. The total resource reaches 47.1

million m<sup>3</sup>, the inferred re-source is 388.510 million m<sup>3</sup>.

Quartz crystal has been known in 29 deposits and occurrences, with a scattered distribution in several provinces of north and central Vietnam.

### 2.3) Construction materials

Brick and tile clay has been so far investigated in nearly 200 mines, deposits and occurrences distributed across the whole country with the total resource estimated at 2.5 billion m<sup>3</sup>. It has been found in Holocene fluvio-marine formations, and in the weathering crust of Neogene terrigenous formations.

Cement clay has been found in over 40 investigated deposits and occurrences with the total resource of over 11 billion tons. They are of the following genetic types: weathering from Triassic terrigenous formations; sedimentary in Holocene fluvio-marine and fluvial formations.

Pozzolan was formed on weathered metamorphic schists, on the sediments of chemical, organic, and biochemical geneses, having high SiO<sub>2</sub> and amorphous silica contents. It is distributed in the territory of Quang Ninh, Thai Nguyen, Nghe An, Quan Binh, and Thua Thien Hue Provinces together with porous rocks and volcanic tuffs. The investigated resource of 5 deposits reaches nearly 200 million tons.

Limestone has been classified into the following types: organic limestone composed of quaternary mollusk shells and corals existing in the coastal zone, biochemical limestone of great potentiality distributed in Bac Bo, North Trung Bo, and West Nam Bo; among them the most valuable is limestone of the Carboniferous-Permian Bac Son Formation and Triassic Dong Giao Formation. Its indicated and inferred resources (B+C<sub>1</sub>+C<sub>2</sub>) of 91 mines, deposits and occurrences approximate 13 billion tons, and hypothetical resource estimated at hundreds of billion tons.

Construction and facing stones have been found in intrusive magmatic rocks of high quality. Among 76 investigated deposits, there are 16 explored deposits which give a reserve of 1.611 billion m<sup>3</sup> of construction stone and 241 million m<sup>3</sup> of facing stone. From effusive rocks, among 52 investigated deposits, there are 15 explored deposits which give a reserve of 358 million m<sup>3</sup> of construction stone and

24 million m<sup>3</sup> of facing stone. Apart from these, sedimentary and metamorphic rocks also have a large resource.

## 3) Energy resources

### 3.1) Oil and gas

Oil exploration with the Soviet assistance, lead to a discovery of petroleum in 1987 at Bach Ho, southeast of Ho Chi Minh City, followed by the discovery of other offshore oilfields. Vietsovpetro now operates several wells at Bach Ho and Dai Hung. In 1992, the output of crude oil was around 3.5 million tons, with the bulk of the output exported. In 1989, discovered Vietnamese oil resources have been estimated at more than 1,000 million tons. Vietnam also has sizeable natural gas reserves: roughly 30 billion m<sup>3</sup> at the Bach Ho (White Tiger) oilfield and 66 billion m<sup>3</sup> at the Dragon and Dai Hung (Big Bear) fields. The country's petroleum potential is considerable, including: 1) Mekong and Red River estuaries (on and off-shore); 2) The coastal area between Hue and Nha Trang and 3) A huge area between southeast Vietnam and the Spratly islands (where Vietnam is in dispute with both China and the Philippines over sovereignty of these tiny islands). Several foreign companies are now engaged in exploration of these areas under a "production sharing agreements".

### 3.2) Coal

Coal in Vietnam has been classified into 5 types: high, medium and low metamorphism, medium metamorphism, and non metamorphic (peat). However, in accordance with its usage, peat is considered within the group of chemical and fertilizer materials. The group of coal of high metamorphism is composed of meager coal, semi-anthracite and anthracite, having greatest value in East Bac Bo, which includes the Bao Dai and Hon Gai coal basins. There are 82 coal mines and deposits (A, B and C<sub>1</sub> categories) in Thai Nguyen, Ninh Binh, Son La and Lai Chau Provinces. The demonstrated reserves of 37 coal mines and deposit of this group reach nearly 20 million tons. The group of low metamorphism coal comprises lignite and different brown coals, with demonstrated reserves of over 100 million tons, apart from



the deposits in the Hanoi Depression. According to drilling from petroleum investigation, this depression has the largest hypothetical resource of Neogene lignite in the country, reaching up to 250 billion tons.

### 3.3) Uranium

Various uranium deposits and occurrences have been discovered in northeast Vietnam, central Vietnam and Tay Nguyen Highlands. According to the classification of OECD and IAEA, uranium mineralizations in Vietnam can be divided into 6 types: uranium in sandstones, vein and vein-like uranium deposits, uranium in effusive rocks, uranium in metamorphic rocks, uranium in coal and uranium in Quaternary sediments.

### 3.4) Groundwater resources

There are about 400 sources of mineral and thermal water; among them 287 sources have been investigated and sampled for analysis. Up to the end of 1996, 28 sources had passed through exploration, giving a total indicated resource of 3,916 m<sup>3</sup>/day, resource of C1 rank: 14,372 m<sup>3</sup>/day, and of C2 rank: 4,481 m<sup>3</sup>/day. Almost all provinces have their own mineral water sources, which can be classified into 12 types, such as: carbonated, siliceous, fluoride, hydrosulphide, bromic, iodine, boric, ferruginous, arsenic, radium, mineralized and thermal waters.

## History and current status of exploration and mining in Vietnam

Copper, zinc, tin and gold have been mined in Vietnam since the Bronze age, and silver, iron and some non-metallics (especially kaolin) probably since the 1st century B.C. They were extracted mostly by Chinese miners, migrating to Vietnam especially under the Ming dynasty; "Chinese workings" are found on numerous mineral deposits.

Exploitation of the country's mineral resources was intensified under the French occupation of Indochina in 1884. Coal, gold, tin, chromite, zinc, antimony, apatite, talc and some other minerals were exploited from the beginning of this century, mainly for export to France. Some industrial minerals were produced for local use: cement and construction

materials, dimension stones. During the 2nd World War, practically all mineral exports were directed to Japan.

After the achievement of independence (in 1954), in north Vietnam, vigorous exploration and restoration of the mining industry was carried out with assistance from eastern European countries and China. Restored mines included the Hon Gay coal mines, Lao Cai phosphate mines and cement plant in Hai Phong, among others. The Thai Nguyen steel plant was also built and production of iron ores started during this time.

After the re-unification of the country in 1975, exploration has been continued, led by Vietnamese geologists. Several important deposits were discovered in the south (bauxites, mineral sands, see [5]). Oil exploration with Soviet assistance led to discovery of petroleum in 1987; an oil refinery, located near Ho Chi Minh City, came on-stream in 1988.

At present, Vietnam produces approximately 3.5 million tons of crude oil/year and its mineral production includes: coal (about 10.7 million tons/year), cement (1.6 million tons), phosphate (300,000 tons), chromite (3.5 million tons), iron ores, gold (around 1,000 kg, including production by the local population) cassiterite (3,000 tons), graphite, kaolin and many other minerals produced to serve domestic demand. Several foreign companies are involved in oil exploration (BP, Total, BHP) as well as in prospecting (seldom in exploitation) for minerals (mainly Australian companies).

## Conclusions

Different geological surveys have showed that Vietnam is well endowed with a wide range of mineral resources. The country has some of the world's largest resources of apatite, bauxite, rare earths, and large, commercially viable deposits of oil, coal, gold, gems, copper, zinc, tin, chromite, manganese, ilmenite (mineral sands), graphite and other minerals.

However, in spite of its massive potential, the country's mining sector is still underdeveloped and many available mineral reserves remain unexploited. This situation is now changing. Recent, but increasing involvement of foreign companies in the Vietnamese minerals sector

will accelerate the development of high-value and/or export-orientated minerals. Finally, the country's fast-growing economy will surely stimulate domestic demand.

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