

# Mineral resources of Vietnam

Imrich Kušnir<sup>1</sup>

## Nerastné suroviny Vietnamu

Vietnam je bohatý na nerastné suroviny, ktoré sa nachádzajú prevažne na severe krajiny. Ložiská bauxitov, fosfátov, vzácnych zemín (REE), majú svetový význam. Ale i zásoby celého radu ďalších surovín (ropy, uhlia, zlata, železných rúd, chromitu, cínu, ilmenitu, medi, grafitu, atď.) sú významné, ekonomicky ťažiteľné a ich potenciál je obrovský. Za uvedené nerastné bohatstvo je „zodpovedná“ rozmanitá geologická stavba krajiny. Taktiež i morfológia a klíma (vlhká, tropická) prispeli ku vytvoreniu niektorých ložísk (bauxity v krasových priehlbniach, atď.). Súčasná produkcia, okrem ropy (3,5 Mt/rok), zahŕňa: 10,7 Mt uhlia, 3,5 Mt chromitu, asi 1 000 kg zlata, grafitu, kaolínu a mnohé iné minerály. Napriek tomu, je banický priemysel v porovnaní so surovinovou základňou slabšie vyvinutý. K jeho rozvoju určite prispeje i účasť zahraničných spoločností, odnedávna prítomných pri prieskume a ťažbe surovín určených pre export.

Okrem stručného úvodu do geológie krajiny, obsahuje tento článok krátky popis nerastného bohatstva Vietnamu.

**Key words:** Vietnam, Indochina, Indochinese shield, Indosinian orogeny, mining, mineral resources, petroleum, coal, phosphates, gold, bauxites, zinc-lead, mineral sands, rare earths.

## Introduction

Vietnam, with an area of 335 000 km<sup>2</sup>, occupies the eastern side of the Indochinese peninsula (fig. 1). It is formed of a narrow (locally only 40-70 km) band of land, extending over 1 500 km along the Chinese sea. Most of the northern Vietnam (Tonkin) and the centre of the country (Annam) are mountainous, reaching 3 142 m in the Fan Si Pan massif, near the Chinese border. The climate is tropical, humid. Infrastructures in Vietnam remain poor. Some 70% of the country's fast-growing population of 68 millions are engaged in agriculture. Rice is the main staple, produced principally in the vast deltas of the Mekong and Red rivers. The country is well endowed with mineral resources, located mostly in the north. The present mineral production includes various minerals (coal, phosphate, cement, iron ores, chromite, gold, tin, kaolin, etc.) and oil. However, in comparison with the country's mineral wealth, the mining sector is underdeveloped. This article presents a brief overview of the main mineral resources of Vietnam and their potential, as well as an outline of the country's geology.

## Geology of Vietnam

The geological exploration of Vietnam began after the French occupation of Indochina, at first aiming mainly at the discovery of minerals. The Geological Survey of Indochina was set up in 1985 and first geological studies occurred in the 1910-20 (see Mansuy, 1912; Deprat, 1916; Bouret, 1922, etc.). The geological map at 1:400 000 of the Northern Vietnam was published in 1927 and that of Indochina at 1:2 000 000 in 1952 (Fromaget & Saurin, 1952). A major work on the geology of the peninsula was published in 1941 by Fromaget, reflecting the ideas of the French scientists on the structure of the region. In the late 1950s and 1960s, the Northern Vietnam was vigorously explored with the assistance of the eastern European countries (essentially Soviet Union) and China; its geology was re-examined and a new geological map at 1:500 000 published (see Dovzikov, 1965). Afterwards, the geological survey was focused mainly on the exploration of minerals, carried on by the Vietnamese geologists and on the oil exploration with the foreign assistance.

**Regional geological setting.** Vietnam is constituted mainly by the folded belts surrounding two shields, cratonised in the Upper Proterozoic: the Yangtze craton and the Indochinese shield, located in the Mekong basin and occupying most of Cambodia and the contiguous parts of Laos and Vietnam (Fromaget, 1941; Sang & Ho, 1990, fig. 1). 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. The indosinian folding domain occupies most of the North Vietnam, down to the Ca river fault. With the latter orogeny, considered to be the most important of Indochina, was achieved the stabilisation of the region. However several "active" structures (troughs/grabens) have been formed in the Mesozoic (Tu Le, Sam Nua, Dalat troughs) and in the Cenozoic (eg. Hanoi, Cuu Long grabens, see Dovzikov, op. cit., fig. 2).

**Stratigraphy** (fig. 3). The substratum of Vietnam is formed by various rocks of precambrian to quaternary age. The precambrian formations occur in the Kontum massif, extending over most of the central Vietnam, and in the north of the country, principally along the Red river (fig. 2). The crystalline rocks (migmatites, orthogneisses) cropping out between the Song Chay and Red rivers, are considered to be of a probable archean age.

<sup>1</sup> Imrich Kušnir, 22, av. de Guyenne, F-92160 Antony, France  
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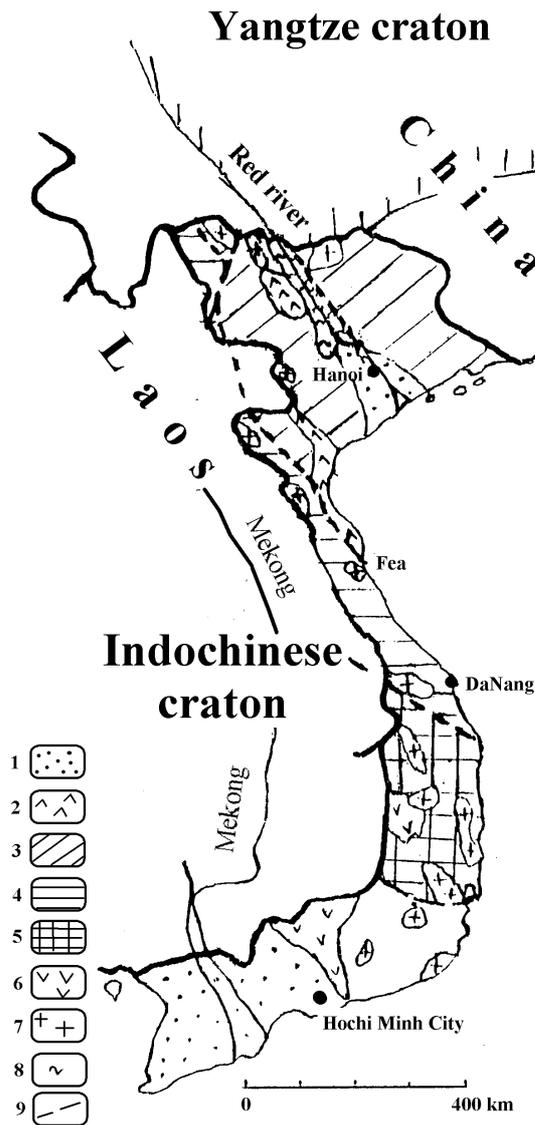


Fig.1. Tectonic map of Vietnam. 1-Cenozoic troughs, 2-Mesozoic troughs, 3-Area of Indosinian folding (Lower Triassic), 4-Area of Late-hercynian folding (Lower Triassic), 5-Kontum massif, 6-Trap basalts, 7-Granite massifs, 8-Proterozoic, 9-Faults.

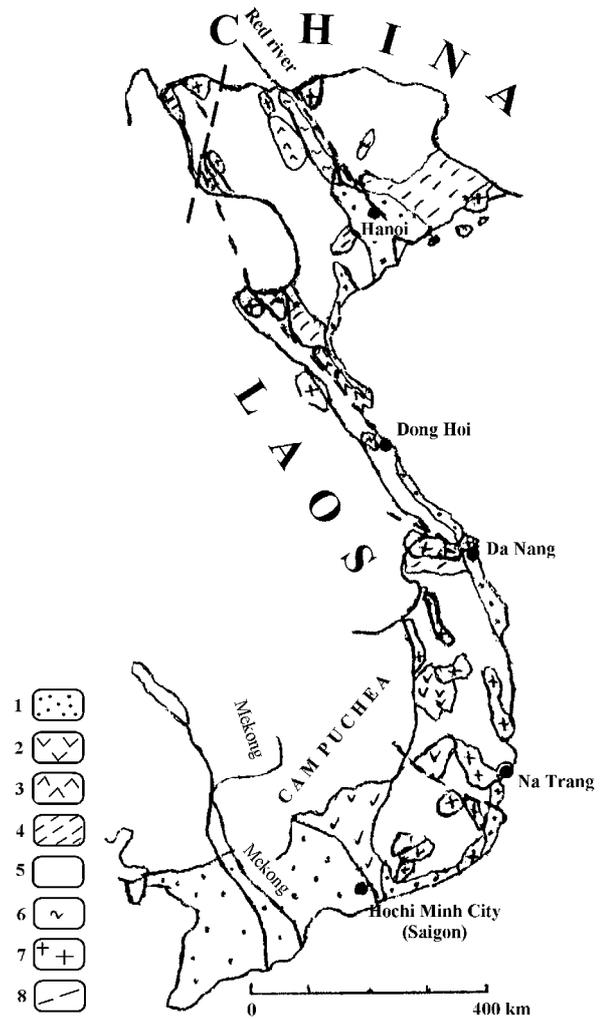


Fig.2. Simplified field geological map of Vietnam. 1-Quaternary, 2-Basalts (traps), 3-Jurassic - Cretaceous, 4-Triassic, 5-Paleozoic, 6-Proterozoic, 7-Granites, 8-Major faults.

Paleozoic formations are quite spread in Vietnam. They comprise cambrian series, thick silurian formations (schists, sandstones ...) and devonian and permo-carboniferous limestones, covering vast areas in Annam and the northern Vietnam, extending to China. Lower and middle triassic series are mainly terrigenous (schists, sandstones) and volcanic. After the indosinian orogeny, during the Norian, continental series, containing large coal deposits in the northern Vietnam, were laid down. In the troughs formed in Jurassic and Cretaceous, thick continental series and volcanics were piled up. Tertiary and quaternary formations are deposited in several grabens & troughs, the most important of which are located in the Mekong and Red rivers deltas. Pliopleistocene tholeiitic basalts (traps) form vast plateaus in southern Vietnam (fig. 2).

**Magmatism, intrusive rocks.** Proterozoic intrusives comprise granites of the Chu Lai and the Tumorong massifs, in the southern Vietnam, dated of 2 300 Ma (Nguyen, 1988) as well as the basic rocks of the Bao Ha - Ca Vinh complexes and the granitic rocks, often gneissic, of the Song Chay massif in the north. Several phanerozoic intrusive/magmatic series, have been distinguished:

- Upper paleozoic, including granites (ex. Loa Son, Dien Binh massifs, in the south, dated 250-360 Ma, see Nhan, 1988, and Nam Rom, Moug Lat massifs in the NE, yielding K/Ar ages between 252 and 268 Ma - Dovzikov, 1965), basic rocks (Vithulu complexe) and permian effusions;
- Triassic, emplaced during the indosinian orogeny, most widely spread in Vietnam, comprising a large variety of rocks, from ultramafic (ex. Bang Xang, Nui Nua massifs) to granitic intrusives (ex. Vanh Canh in Kontum and Pia Bioc in the north of a K/Ar age between 215 and 240 Ma);

➤ Upper Cretaceous-Paleogene, comprising alkaline, effusive rocks, granites (Pia Oac, Dinh Quan massifs, 98 and 86 Ma, Fan Si Pan, 33-56 Ma), syenites (Nam Se, 40-56 Ma) as well as some gabbros and peridotites.

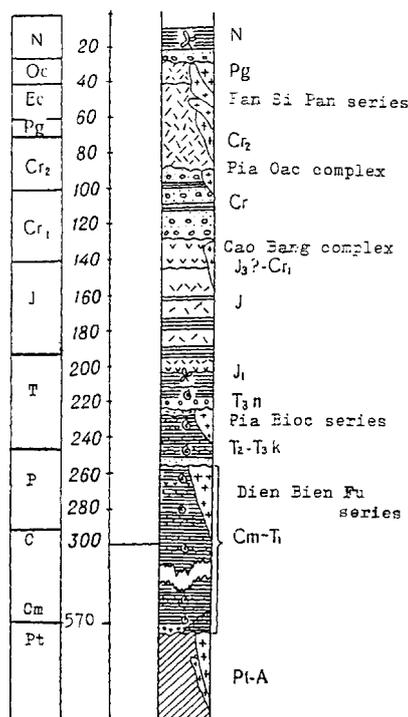


Fig.3. Stratigraphy of the vietnamese sedimentary and magmatic formations Adapted after Dovzikov).

## Mineral resources

### History of exploration and mining, present mineral production

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. The exploitation of the country mineral resources was intensified after 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 the export to France (Blondel, 1931). Some industrial minerals were produced for a local use: cement and constuction materials, dimension stones. During the 2nd world war, practically all mineral export was directed to Japan. After the achievement of the independance (in 1956), in the Northern Vietnam, a vigorous exploration and the restoration of mining industry was carried out with the assistance

of the eastern European countries and China. Were restored, between others: Hon Gay coal mines, Lao Cai phosphate mines and cement plant in Hai Phong. Then the Thai Nguyen steel plant was built and production of the iron ores started. After the re-unification of the country in 1976, the exploration has been carried on by Vietnamese geologists. Several important deposits were discovered in the south (bauxites, mineral sands, see Xing, 1988). Oil exporation with soviet assistance, lead to a discovery of petroleum in 1987; an oil refinery, located near Ho Chi Minh City, came on line in 1988. At present, Vietnam produces approximately 3,5 Mt of crude oil/year and its mineral production includes: coal (about 10,7 Mt/y), cement (1,6 Mt), phosphate (300 000 t), chromite (3,5 Mt), iron ores, gold (around 1 000 kg, including production by the local population), cassiterite (3 000 ? t), graphite, kaolin and many other minerals produced for the local market/use. Several foreign companies are involved in the oil exploration (BP, Total, BHP) as well as in prospecting (seldom in exploitation) for minerals (mainly Australian companies).

### Ferrous metals

**Iron.** The most important Vietnamese iron deposit is Qui Xa, near Bao Ha in Hoang Lien Son province in the north of the country, close to the Hanoi - Lao Cai railway (fig. 4). The ore, mostly magnetite (martite) and limonite, contains 54-60% Fe (average 55% Fe + 2-4% Mn). The total proven reserves stand at 118 Mt, recoverable by open pit, practically without overburden. The deposit was formed in a large karst cavity in the devonian limestones, filled up by a material (including hematite & magnetite) from weathering/erosion of the archean (?) BIF occurring along the Red river, between Yen Bay and Lao Cai. The ore results from oxidation/enrichment of the cavity's infill (Glazek & Juskoviak, 1964).

The Trai Cau mine, also located in the north, supplies ore to the nearby (20 km) Thai Nguyen iron and steel works of a capacity of 400 000 t/y. The deposit is represented by lenses of magnetite, 20-200 m long and 5-10 m thick, on the contact of the permo-carboniferous limestones with diabase dikes. The average ore grade is 53% Fe. On the western extension of the mineralised zone, occur several deposits of limonitic ores, containing about 47% Fe and 3-5% Mn. The proven reserves of the Trai Cau area are 44 Mt of ore (Kusnir, 1967).

There are numerous smaller deposits and occurrences of the iron ore scattered over the country, e. g. Mot Sat and Ban Lang (skarn) near Cao Bang, Qung Tin etc. Estimated reserves of the country's iron ore are 700 000 t with Fe content of 60% (Min. Ann. Rev., 1992).

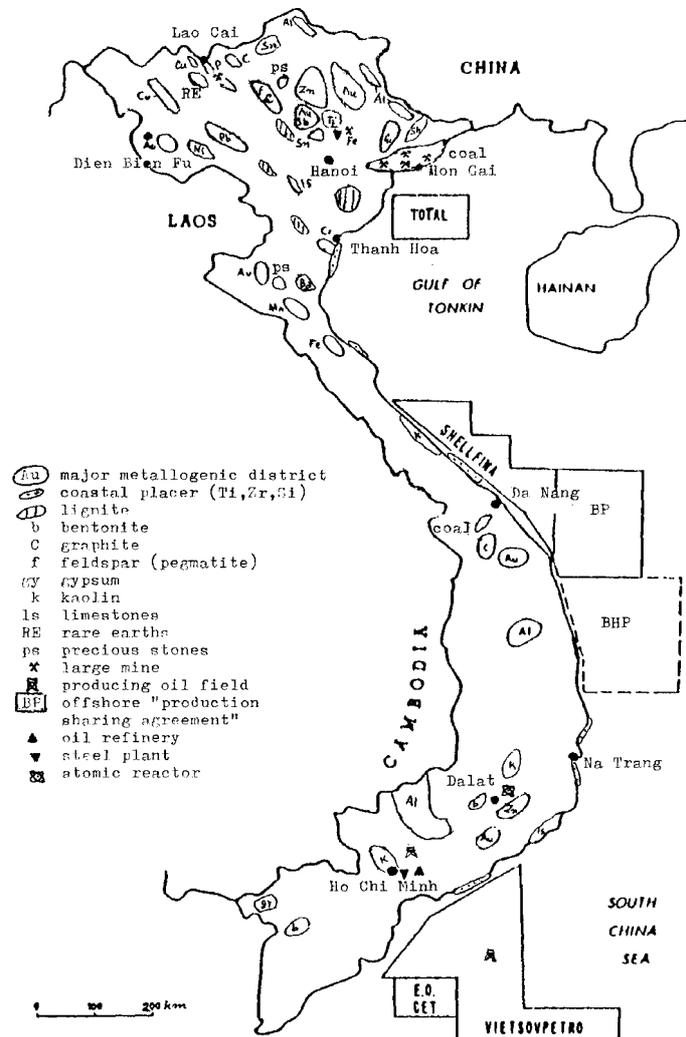
**Manganese.** All important manganese districts are located in the north of Vietnam. Vein type occurrences include Hai Hung (or Nien Son), to the north of Hai Phong and Yen Cu, SE of Vinh. Yen Cu deposit, with possible reserves of 2,5 Mt of high grade ore (10-15% Mn, Xinh, 1988), is presently mined. It is a vein of psilomelane and limonite, 0,5-4 m thick, hosted in the devonian schists. Lang Bai residual deposit is being

assessed for its gold potential (up to 2 g/t Au). In the Cao Bang area, near Chinese border (at Toc Tac, Ban Khuong etc), manganese occurrences are of sedimentary origin, hosted in the devonian limestones. At Toc Tac, the bed 0.2-2 m thick, contains about 1 Mt of rich ore (38-40% Mn for weathered, enriched zone, 20-23% for primary ore). The ore minerals are psilomelan, pyrolusite, braunite as well as Mn-carbonates. The deposit is mined for the manufacture of batteries.

**Chromite.** Alluvial deposits of chromite around Nui Nua ultrabasic massif (15x4 km) in the Thanh Hoa province have been mined since 1930. In 1963, production from Co Din deposit peaked at 36,000 t of concentrate; today's production is about 3,500 -4,000 t/y (Premoli, 1989). The placer, in the quaternary plain, is about 1 km large. The lensoidal orebodies consist of pebbles, gravels and clays. Reserves of 20,8 Mt of chromite and contents of 1,5 to 5% Cr<sub>2</sub>O<sub>3</sub> have been reported in a bed over 8 m in thickness (Xinh, op. cit.). Cr<sub>2</sub>O<sub>3</sub>/FeO ratio is 2,2-2,4, but most of the chromite is fine grained (70-280 microns), therefore unsuitable for metallurgical uses.

**Nickel.** The most important nickel deposits are located near Ta Khoa, on the Son La (Black) river. Mineralisation of nickel and copper sulphides (mostly pentlandite, chalcopyrite, violarite) occurs at the base of small serpentinised peridotite massifs and in the surrounding calc-silicate rocks. The Ban Sang deposit, prospected in the 1960s, contains about 3 Mt of ore grading 0,93% Ni, 1,2% Cu, some cobalt and traces of Te, Se and Au. High grade mineralisation, up to 7% Ni, has been reported at Ban Phuc (Min. Mag., 1997). Several similar occurrences are found in the Cao Bang area, in the north of Vietnam (e. g. Bao Lac).

Fig.4. Mineral resources of Vietnam. ⇒



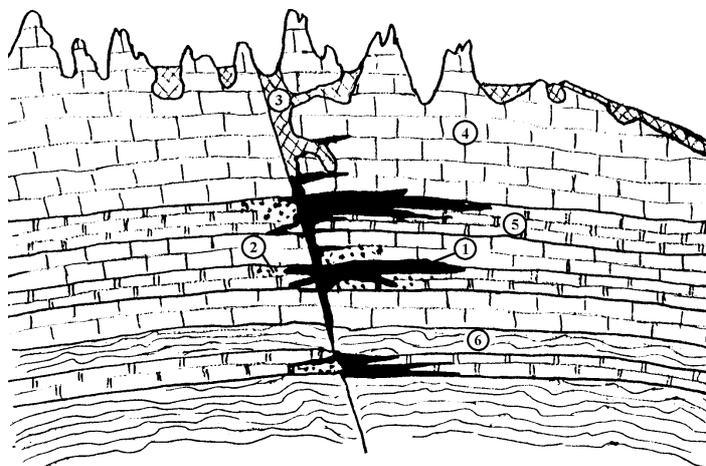
The ophiolitic belt along the Ma river suture - "trace de cicatrice" of Fromaget, op.cit.), between Thanh Hoa and Ta Khoa, is considered to have a significant nickel and chromite potential.

**Non-ferrous metals**

**Copper.** Major copper occurrences are found in three areas in the North Vietnam: west bank of the Red river, between Lao Cai and the Chinese border, Luc Ngan river basin in the northeast and the Son La - Son Da rivers area in the northwest (fig. 4). The most promising seems to be the Lao Cai area, where is located the Sinh Quyen deposit, found in the 1960s. Its mineralisation is represented by lenses, several meters thick and a few hundred meters long, of magnetite, chalcopyrite, pyrrhotite, pyrite and orthite in the hornblendite dikes. The ore is grading 0,5-2,5% Cu, about 2 g/t Au and some nickel. The area potential is estimated at 200 000 t of copper. In the Luc Ngan and the Son La - Son Da rivers areas, the mineralisation is stratabound, occurring in the triassic sandstones. In the former area, mineralised outcrops are found between Bien Dong and Cam Son, distant of about 15 km. Near Cam Son, the mineralised beds, 50m to 1,2 km long, are 0,5 to 7 m thick and contain 0,5-0,6% Cu. At Bien Dong, the Cu content is higher (0,7-1,5%, cf. Kusnir, 1967).

**Zinc-lead** (+ Ag, Cd, In, Ga, Ge). Vietnam has a good zinc-lead potential. Most of the occurrences and deposits (over 150) are located north of Hanoi, between Tuyn Quang and Ngan Son and are hosted in the paleozoic limestones. Rich secondary ores (25-48% Zn) have been exploited by the French from Cho Dien deposit (Fig.5), situated about 40 km NW of Ba Kan. In the 1960s, some 425 000 tons of zinc and 87 000 tons of lead (+ some silver, cadmium and indium) have been found in the oxide (predominant) and sulphide ores (Kusnir, 1964). The stratabound sulphide ores (mainly sphalerite, pyrite and galena), occurring in the givetian metamorphosed limestones, average 10% Zn and 3.5% Pb. The secondary ores (hemimorphite, smithsonite,

beudantite ...) are found principally in the karst cavities. Their average grade is 15,9% Zn and 2,8% Pb. They are presently exploited; a small plant produces zinc oxide for the domestic use. Na Tum deposit, only 9 km from Cho Dien, has about 12 Mt of ore grading 15% Zn+Pb. Lang Hit deposit, located 18 km north of Thai Nguyen, is quite alike Cho Dien. Its reserve is 1 Mt of ore at 8,5% Zn and 3,5% Pb (Kusnir, 1967). Similar Zn-Pb mineralisation is found near Vinh (Le Thuy) and Than Hoa, as well as to the southwest of Dalat.



←  
Fig.5. Types of mineralisations at Cho Dien Zn-Pb deposit. 1-Massive sulphides (Zn-Pb), 2-Disseminated sulphide ores, 3-Oxidized ores, 4-Limestones (Givetian), Schistoce limestones, 6-Phyllites (Eifelian).

In the northwestern Vietnam, e.g. near Dien Bien Phu and Tu Le, located some 50 km from Ngia Lo, occurs a vein-type, predominantly lead mineralisation. At Tu Le, veins, 0.5-1m in thickness, up to 600 m in length (Co Gi San deposit), consist principally of the silver-bearing galena (4-5 kg/t Ag). They are hosted in the slightly metamorphosed, volcano-sedimentary rocks of Triassic and Lower Jurassic. Ore grades vary from 4 to 6% Pb and 1 to 2.5% Zn.

**Tin and tungsten.** The present production of cassiterite is estimated at 2 000 t/y, all from alluvial operations that reserves are put at 85 000 tons (Min. Journal, 1995). Main stanniferous areas are: Pia Oac and Tam Dao in the north and Qui Hop - Dalat in the south. Two first areas, situated in the same geological setting as the south Chinese tin province (Da Chang), has the best potential. Primary mineralisation (mainly quartz veins with wolframite, cassiterite and a little molybdenite) is genetically related to the cretaceous granites. Economically important are the alluvial deposits, often formed in the karst cavities/depressions. Tin Tuc deposit in the Pia Oac area, located close to the Chinese border, contains some 16 000 t of cassiterite; grades up to 12 kg/m<sup>3</sup> have been found at the base of alluvium. In 1963 (i. e. after their discovery), the reserves of the placers around Song Duong massif in the Tam Dao area, situated SE of Tuyen Quang, were estimated at 7 000 t of tin (Kabakov, 1963).

**Aluminium** (bauxite). Two different types of bauxite occur in Vietnam: sedimentary, found mostly on the karstified permo-carboniferous limestones overlaid by triassic argillites, and the "lateritic" bauxite, formed by weathering of basalts. The first type occurs mostly in the NE of the country, in a zone extending over some 200 km, from Lang Son to Dong Van (and continuing to China). The Bo Phun deposit, situated near the Cao Bang township, is quite representative of this type. Its dimensions are: 2,7 km x 500 m x 4-6 m. It contains about 10 Mt of reserves grading almost 50% Al<sub>2</sub>O<sub>3</sub>. Total reserves of the area are estimated at 1 000 Mt (Gazenko, pers. comm.).

The lateritic bauxites are developed mainly in the southern Vietnam. Between Ho Chi Minh City, Boun Ma Thout and the Cambodian border, they cover more than 20 000 km<sup>2</sup>. The weathered horizon over the basalt can reach 60 m and bauxite resources are very large, of the order of 4 000 Mt (Xinh, 1988). The average grade is 36-39% Al<sub>2</sub>O<sub>3</sub>, 5-9% SiO<sub>2</sub>, 25-29% Fe<sub>2</sub>O<sub>3</sub> and 4-9% TiO<sub>2</sub>, but it can be easily upgraded by washing. The Dac Nong deposit (one of five explored areas) has proven reserves of 103 Mt of ore.

**Antimony.** Vietnam has substantial antimony resources, found, with the few exceptions, in the north-eastern part of the country (Quang Nhai, Quang Tin are in the south). Most of the country's antimony mineralisation is associated with gold. The largest known mineralisation occurs in the Chiem Hoa area, located 25 km SW of Cho Dien Zn-Pb deposit. It was discovered in 1962. Stibnite (+ minor pyrite, arsenopyrite and gold, cf. Waleczek, 1964) is found in quartz veins at Lang Vai, Dam Hong, Pa Kha, Na Mo, Tho Binh and Hoa Phu. The Lang Vai Sb-Au deposit, intermittently explored since its discovery, has some 5 000 tons of Sb. Currently, it is being mined. Antimony mineralisation is also known: northeast of Hon Gay (at Dong Mo), near Lang Son (Tat Khe, Tan Mai) and in the Tanh Hoa and Nge Tinh provinces (Tai Bao, Ta Soi ...).

**Titanium (ilmenite) and zircon.** Ilmenite occurs in Vietnam in primary deposits and in placers. The former are found in gabbroic Nui Tchoua massif, situated northwest of Thai Nguyen. It consists of layered ilmenite dissemination (30-70% FeTiO<sub>2</sub>) at the base of the gabbro. In the Tram and Phu Long deposits, the layers 5-10 m thick and 400-500 m long, contain 10-15% TiO<sub>2</sub> and 0,1-0,3% V<sub>2</sub>O<sub>5</sub> (cf Kusnir, 1967). The proven reserves are 2,8 Mt. Alluvial placers around the massif have not been explored. 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 coastline, stretching over some 1 500 km (fig. 4). 21 major and medium sized occurrences have been delineated. The reserves of Cat Khanh deposit, south of Nha Trang, are set at 1,59 Mt of ilmenite and 32 000 t of zircon. The Quang Nam deposit, in the vicinity of Hue, has about 5,4 m<sup>3</sup> of

mineralised sands averaging 5% heavy minerals; its reserves are: 212 000 t of ilmenite, 49 000 t of zircon and 10 800 t of monazite and xenotime (Tremoli, 1990).

### Precious metals and stones.

**Gold.** Gold has been mined in Vietnam since immemorial times. At present, its production is probably about 1 t/y, part of which is produced by the local population (panners). Eight major gold fields are known in the northern Vietnam and two in the south. In the Chiem Hoa area, gold mineralisation consisting of native gold and calaverite is associated with stibnite (see Antimony). The large Lang Vai Au-Sb deposit contains several tens of tons of gold (Xinh, 1988). Placers (eg. Na Dzian) and auriferous quartz vein occurrences (Pac Lan deposit) are known in the Ngan Son - Cao Bang area, in Vinh Phu province (Kim Boi, Cho Binh deposits) and to the south of Thanh Hoa (at Phu Qui and Lang Chau). Near Cua Rao in the Nge Tinh province, the alluvium of the Nam Chou river contains 1-5 g/t Au over some 8 km (Kabakov, 1963). The rich (10-15 g/t Au) Bong Mieu deposit, located about 80 km S of Da Nang (fig. 4), was exploited by the French (Blondel, 1931). A reserve of 5 t Au has been found by a recent exploration (Min. Ann. Rev., 1995). The mineralisation comprising native gold, auriferous pyrite and minor galena in quartz veins, 3-4 m in thickness, is hosted in gneisses. As already mentioned, several antimony, copper, manganese and iron deposits contain gold.

**Gems.** Rubies and sapphires of an excellent quality are found in alluvium of several streams at Luc Yen, NW of Hanoi (in the Ha Tuyen province) and around Qui Chau, SW of Thanh Hoa. Cutting and polishing is done in a factory in Hanoi.

### Industrial minerals

**Phosphates.** Some 90 deposits of phosphates are known in Vietnam, mostly in permo-carboniferous limestones in the northern Lang Son, Nge Thin and Thanh Hoa provinces. Several of them are exploited for a local use. The biggest phosphate resources are in the Lao Cai deposit, located on the western side of the Red river. The apatite beds are the metamorphosed phosphorites, hosted in the cambrian metasediments (schists, marbles ...), occurring over 100 km in Vietnam (and continuing in China). Total reserves of phosphate are put at 1 700 Mt (Xinh, 1988). The mined bed is 10-20 m thick. Four categories of ore are produced; the richest one contains 36-41% P<sub>2</sub>O<sub>5</sub> and the poorest below 16% P<sub>2</sub>O<sub>5</sub>, essentially in collophane. The ore is shipped to the super-phosphate plant at Lam Thao (Viet Tri).

**Graphite.** The Lao Cai region also contains the most important Vietnamese deposits of graphite. They occur on the eastern side of the Red river, in an area of 9 x 11 km. The graphite orebodies are hosted in the precambrian rocks (calc-alkaline gneisses, amphibolites, mica-schists) or in the pegmatites. The proved reserves of the area are 3,78 Mt of graphite and the ore grade is 5-12% C (Xinh, op.cit.). One example of the area deposits: Nam Tri, prospected in the 1960's, situated 6 km E of Lao Cai. The graphite bed, 20 m thick and 1 km long, is hosted in a pegmatite. The ore grades 14% C in average. Several deposits are found around the Yen Bay township, SE of Lao Cai. They are mined for the domestic market. Reserves of crystalline graphite of this area are estimated at 1.3 Mt. Its potential is huge. In the southern Vietnam, graphite occurs over an area of 12 x 7 km, near Hung Nhuong, S of Da Nang, in the precambrian sillimanite-garnet schists. Probable and proved reserves of six main orebodies stand at 2,5 Mt of contained graphite plus 1,8 Mt of sillimanite (Premoli, 1990). Two types of ore are mined: massive with 30-50% C content and low grade averaging 6-8% C.

**Feldspar, muscovite and beryl** (pegmatites). Most of the known pegmatites occur along the Red river tectonic lineament, between Lao Cai and Phu To. They are hosted in the precambrian (archaen ?) rocks, but they have yielded cretaceous K/Ar ages (69-79 Ma, cf Kusnir, 1967). They are composed essentially of feldspar, quartz, mica (mostly muscovite), tourmaline and beryl. Some of them are of quite important dimensions, eg. Lu Phu pegmatite, near Phu To is about 500 m long and 7-9 m thick. Most of current feldspar production comes from the Thach Khoan deposit (3 000 t in 1985, see Premoli, 1990). Beryl (not of gem quality) was first discovered during the exploitation of kaolin from this deposit.

**Kaolin.** Vietnam is well endowed with kaolin (and refractory clays); their formation from the rocks with a high alumina content (pegmatite, syenite, etc.) is facilitated by a humid, tropical climate. The deposits of a very good quality permitted the development of the ceramic industry for centuries. Presently, kaolin is mined in six major districts dispersed throughout the country (fig. 4), comprising: Red river (eg. Thach Koan deposit, see above), Hai Hung province, SE of Hanoi (ex. Ha Duong, kaolin on keratophyre, Tri Linh, clay) and Dalat. Reserves of the individual deposits range around tens of Mt grading about 30% Al<sub>2</sub>O<sub>3</sub>.

**Barytes.** Veins of baryte, up to 3 m thick and 50-150 m long, containing sphalerite and galena, were reported from the Nghe Tinh province. They occur in shear zones over a strike of approximately 60 km. At two deposits (Bao Khe, Ngia Lam) the average grades are above 75% BaSO<sub>4</sub>. Thick baryte veins are found also SE of Tuyen Quang in the Bac Thai province (eg. Cho Ra, Ngai Thang). Baryte is an important component of the large rare earth deposits near the Chinese frontier (see below); reserves of Dong Pao deposit alone are 2,9 Mt.

**Cement.** Vietnam has abundant reserves of limestones of a good quality, suitable for production of cement. Installed cement industry capacity (approximately 3,5 Mt/y) comprises some major plants (Big Son, Hoang

Thach, Haiphong) and numerous mini-plants. The only important gypsum deposit, situated in the Kien Giang province, at the extreme southwest of the country, is mined for the nearby cement industry.

**Silica sand.** Several good deposits of silica sand are found along the Vietnamese coast. The most attractive is Thuy Trieu, 18 km of the Nha Trang township, with 22 Mt reserves of an average grade 98,52% SiO<sub>2</sub> (Tremoli, 1990). The quartz sand, covering an area of 30 km<sup>2</sup>, is between 5 and 15 m above sea level, permitting dry mining.

Vietnam has and produces a large variety of other non-metallics, e.g.: Salt, produced for the domestic use and export; Glass sands, deposits occurring on the islands of Van Sai & Hai Son, formed by weathering of triassic quartzites, are mined for a glass factory in Hai Phong; Talc, hosted in the devonian limestones in the Vinh Phu province, NW of Hanoi. The deposit near Thanh Son is mined; Dimension stones, including marble occurring north of Da Nang and granite, plentiful in the Kontum massif.

**Rare earths** (RE - TR). 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: Mau Xe North and South and Dong Pao. At Mau Xe, tabular or lense-form orebodies are hosted in the permo-carboniferous limestones. The mineralisation is complex, consisting of bastnaesite, parisite, uranopyrochlore, gadolinite, pyrite, apatite and abundant barite 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 Mt of REO, from which 1.7 Mt are proved, at Mau Xe North alone (Xinh, op. cit.). Dong Pao deposit, situated 40 km S has about 7 Mt REO of a similar quality. It is hosted in a paleogene syenitic intrusion (53 Ma).

### Energy resources

**Petroleum.** Oil exploration with the Soviet assistance, lead to a discovery of petroleum at Bach Ho, SE of Ho Chi Minh City, in 1987, followed by the discovery of other offshore oilfields (fig. 4). Vietsovpetro now operates several wells at Bach Ho and Dai Hung. In 1992, the output of crude oil was around 3,5 Mt; the bulk of the output was exported (Min. Ann. Rev., 1992). In 1989, the discovered Vietnamese oil resources have been estimated at more than 1 000 Mt. Vietnam has also sizable 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 Dragon and Dai Hung (Big Bear) fields. The country petroleum potential is considerable, including: 1. Mekong and Red river estuaries (on and off-shore) 2. coastal area between Hue and Na Trang and 3. a huge area between SE Vietnam and Spratly islands (where Vietnam is in conflict of interest with other countries; China and Philippines are claiming sovereignty of these tiny islands). Several foreign companies are now engaged in the exploration of these areas (see fig. 4) under a "production sharing agreements".

**Coal.** Vietnam coal reserves are huge, estimated variously at 20 000 Mt, of which 135 Mt are proved; 3 500 Mt are recoverable (Min. Ann. Rev., 1995). Most of this resource is anthracite of the upper triassic (norian) Quang Yen basin in the northeast Vietnam. The basin, extending over 200 km, west from the coast near Hon Gay (and well-known, world heritage site of Halong bay), has an area of about 5 000 km<sup>2</sup>. The anthracite is of a very high quality with a calorific value of 7 000-8 600 kcal/kg and low ash and sulphur (0,2-1,2% S, 3-7% ash). It occurs in several seams, up to 40 m thick, exploitable by the open pit method (eg. Bang Danh/Ha Tu, Cam Pha, Mao Khe, Co Sau, Uong/Thuong Bi deposits; the latter has some 1 000 Mt of coal, cf Kusnir, 1967). Estimated resources of the basin are 3 300 Mt of anthracite. The Phan Me - Luc Nam basin, to the ESE of Thai Nguyen, contains several small deposits (eg. Bo Ha) of coking coal. The latter is also found in the Song Da basin (at Suoi Bang and Dam Dun) and near Hoa Binh. The northern Vietnam has important reserves of lignite, essentially in the Tuyen Quang basin of a neogene age. Recently, a large resource (estimated at some 100 Mt) of sub-bituminous/brown coal has been discovered during oil and gas exploration in the Red river delta, S of Hanoi (Min. Mag., 1998). In the south of the country, coal occurs in the Nong Son basin, about 30 km SW of Da Nang. A seam, 7-41 m thick, contains coal of the same quality as Hon Gay deposits (Vinh, 1966). In 1997, Vietnam produced 10,7 Mt of coal (mostly from the Quang Yen basin mines) and exported 3.6 Mt, mainly to Japan (Min. Mag., 1998).

### Conclusions

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, bauxites, rare earths, and large, commercially viable deposits of oil, coal, gold, gems, copper, zinc, tin, chromite, manganese, titanium (mineral sands), graphite and other minerals. Certainly, the mineral wealth is related to the country's geology that substratum is built by the formations of Archean to Quaternary age and to its location at the margin of cratons. However, even the morphology and climate (humid, tropical) have contributed to the formation of some deposits (lateritic bauxite, tin placers in the karst depressions, etc.). In spite of the current mineral production including

3,5 Mt of crude oil/y, 10,7 Mt of coal, 3,5 Mt of chromite, 1 t of gold and many other minerals, the country mining sector is underdeveloped and many available mineral reserves remain unexploited. This situation is changing. Recent, but increasing involvement of the foreign companies in the Vietnamese mineral sector will accelerate the development of (at least) high value and/or export-orientated minerals, especially as some of the neighbouring countries (Japan, South Korea ...) lack many mineral resources. And the developing Vietnamese economy will surely entail mining of various minerals for the domestic use.

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