NONMETALLICS: DEFINITION, CLASSIFICATION, OCCURRENCE, ORIGIN, UTILIZATION

The term ‘industrial mineral’ is not defined so strictly as the term ‘ore’ which is mostly a source of metal, or as that of ‘fossil fuel’ (coal, oil, natural gas), which is predominantly a source of energy. In both the latter cases the characteristic feature is the chemistry of the ore (besides the content of impurities, dressability, etc.) or fuel (besides the content of dirt bands, sulfur, etc.). The characteristic features of industrial minerals, however, lie in their physical properties (e.g., fibrosity of asbestos, insulatory properties of mica, the high specific gravity of barite).

In this article raw materials of several types are considered under the term “industrial minerals and rocks”:

1. raw materials that are used in industry in variously prepared forms as minerals (e.g., talc, asbestos, diamond) or rocks (diatomite, bentonite, ochre);
2. raw materials that serve as a source of non-metallic elements (fluorite for fluorine, apatite for phosphorus) or their simple compounds (e.g., borates for $\text{H}_3\text{B}_2\text{O}_3$ or $\text{B}_2\text{O}_3$);
3. raw materials of non-metallic habit that are source of metals, and also of their compounds employed in other than metallurgical industries (e.g., beryl as a source of BeO, magnesite of MgO, bauxite or Al-rich laterite as a source of Al$_2$O$_3$; all these three oxides are refractory materials);
4. building materials (rocks for aggregate, together with gravel and sand for concrete, decorative stone and roofing slate, limestone for cement and lime, brickloam).
Some raw materials have a twofold use. Hematite, for example is ore of iron and simultaneously a component of mineral pigment, or chromite is a chromium ore and component of refractories and abrasive material as well.

Among the endogenous deposits early magmatic ultrabasic kimberlites and ultrapotassic lamproites are source of diamonds - of gem and industrial quality. In the same phase of magmatic differentiates also refractory forsterite - contained in dunite and peridotite - originates, followed later by apatite - source of life-giving phosphorus - in syenite.

**Pegmatites** are the parent rocks of feldspar (for ceramics and glass), piezoelectric quartz crystals, beryl (for Be-alloys), and muscovite (insulation). Pegmatites with these minerals may be accompanied by tungsten, tin and molybdenum or uranium ores.

**Skarn** may include deposits of graphite (refractories, brake linings), chrysotile (refractory textiles) and in carbonate rocks boron minerals (fiberglass, ceramics, glass), and wollastonite (ceramics, filler).

**Carbonatites** - extraordinary carbonate intusives-are accompanied by phlogopite (insulators, filler), apatite and vermiculite (agriculture, insulation).

**Hydrothermal** deposits originating at higher temperatures are graphite in crystalline schists and fluor spar in greisenised granites. Epithermal deposits include fluor spar at the outflows of mineralized waters, and vermiculite formed through alteration of biotite or phlogopite of the parent rock pyroxenite.

**Sublimates** - sassolite (source of boron) in fumaroles and soffiones, and native sulfur of solfatara origin in tuffs of volcanic neck walls - accompany the surficial manifestations of volcanism. **Metamorphogenic deposits** of graphite, alumina rich minerals sillimanite, kyanite and andalusite (all for refractories) were formed by metamorphism of carbonaceous matter (graphite) and bauxite or clay (alumina rich minerals) that was already in place.

Components of all sedimentary deposits are released from their parent rocks by weathering on the Earth surface, which itself gives birth to deposits. Heavy minerals freed by weathering concentrate in mechanical sediments (diamond, corundum, garnet-all a.o. abrasives; monazite - REE, Th), as do also some other minerals (phosphates, feldspar, kaolinitic, montmorillonitic and halloysitic clays, karst bauxites, quartz sand for glass, foundries and building industries). Other exogenous deposits belong to the class of biogenic rocks - guano and diatomite (filtration), or to **biochemical minerals** and rocks: limestone (cement, lime a.o.), sulfur in cap rocks of salt domes, concretionary phosphates in marine sediments, and nitratine (agriculture, explosives). **Volcanosedimentary** raw materials include barite and magnesite (sometimes with huntite). Perlite and pumice (naturally expanded perlite, very porous) - both excellent heat insulators - together with alkaline olivine basalt for melting and casting (or for insulation ‘rock wool’), belong entirely to volcanic products, but their deposits often occur in beds. The sequence of strata of chemogenic rocks begins with gypsum (wallboards) and anhydrite, followed by rocks salt (chemicals), sometimes succeeded by potassium salts (agriculture), and terminates with borates. The recent hydrosphere offers minerals in solution - NaCl, K, B, Br, Mg. All the atmospheric gases - O₂, N₂, Ar, Ne, He, Kr, Xe - can also be used for the benefit of mankind.
DEVELOPMENTS IN THE FIELD OF NONMETALLICS

New applications of nonmetallics as fillers - kaolin, talc, calcium carbonate, mica, wollastonite, silica, diatomite, gypsum - developed for instance in paper-, paint-, plastic-, rubber- and adhesives industries. These minerals act not only as a replacement for more expensive material, but contribute to electrical conductivity, flexural strength, heat resistance or other desired properties. This has expanded the use of products like plastics which have replaced anything from glass milk bottles to steel panels of automobiles. Thin panels of stone as nonload-bearing veneer are used on façades of large buildings, and sulfur is used in pavement and concrete blocks.

Specifications of raw materials become ever more stringent. Fast, automated methods of manufacture demand raw materials of high degree of uniformity. In glassmaking, for example - where there is no “slagging stage“, and what goes in, stays in - precise control of the charge to the furnaces is essential. The same applies to production of high-quality paper using the finest grades of filler and coating material, in manufacture of advanced ceramics and other fields.

Under these conditions processing of raw materials based on knowledge of their physical properties to value added grades is indispensable. Kaolin may be ground and airfloated to produce filler for rubber (with less than Cu 0.001%, Mn 0.002%, Fe 0.15%), waterwashed for use as a filler in paper; or floated, delaminated, calcined and magnetically separated to produce bright lightweight coated grades of paper designed to counter escalating postal rates. Flotation is applied to finely ground sylvite, feldspar, fluor spar, barite, phosphates, graphite, talc, sulfur. Mica and talc may be micronized, i.e., subjected to ultra-fine pulverising.

Progress in mineral raw materials can be expected through improvements in the following methods: ultrasonic method, triboadhesive separation, molecular or ion flotation, ultrasonic sorting, bacterial leaching, etc.

The mineral processor must know the up-to-date methods of mineralogical investigation of nonmetallics - quantitative analytical, grain-size distribution (by means of screens and ultracentrifuge), sedimentary analysis (according to Andreasen, Cassangrande, or Sartorius), character of contacts between minerals, grain shape and intergrowths (important for the dressability), determination of physical parameters of the mineral.

Laboratory methods. High-temperature microscope (to 1700°C) or at least the heating stage (to 1350°C) make possible to observe changes in optical properties of minerals (e.g., feldspars, ganister quartzite) during heating, their phase changes, sintering, melting, recrystallization, reactions in the solid phase, deformations, contraction and dilatation. Important laboratory methods include electron microscopy, scanning electron microscopy, electron diffraction, neutron activation analysis, thermal analytical methods (esp. differential thermal analysis), decrepitation, fluid inclusions study, infrared absorption spectroscopy, gas chromatography, X-ray diffraction, spectrographic quantitative microanalysis (electron microanalysis, proton microanalysis, ion microanalysis, laser microanalysis), flame photometry, atomic absorption spectroscopy, X-ray fluorescence analysis.

Knowledge of colloidal physics is necessary where ultra-finely pulverised particles are studied. Electrostatic separation, optical sorting, and various chemical processes are applied to study industrial minerals. Surface treatment with silanes or titanates is used in plastics
industry to alter the characteristics of mineral filler. This treatment prevents the filler from repelling the resin and maximizes dispersion.

Relative age of industrial mineral deposits as concerns, e.g., the search for new deposits can be based on field observations (intersections of mineral bodies, stratigraphic sequence) or absolute age derived from radiometric and paleomagnetic measurements carried out in the laboratory. The U-Pb method can be used to establish the age of nonmetallic mineral deposits if zircon, sphene, apatite or epidote are present. The Rb-Sr and K-Ar methods are more frequently used in dating of mica, feldspar, amphibole. Paleomagnetic dating requires the presence of magnetic minerals (most often magnetite or hematite) in the deposit under study or in its wall rock formed during mineralization, minimum oxidation or alteration, which may be overprinted by later period of magnetization, and the availability of an accurate polar wandering curve for the continent or plate to which the deposit is confined.

Stable isotope study of asbestos, phosphates, beryl, kaolin and other nonmetallics may explain the phases of genesis.

NONMETALLICS IN WORLD TRADE AND MARKETING

Economics of the industrial minerals and rocks is shortly summarized in Table 1, and in the fact that 60% of all extracted mineral raw materials are nonmetallics representing 40% of the value of all solid raw materials.

The difference between the market structure of the metallic mineral and fuel sector on one hand and the nonmetallics mineral sector on the other is the marked separation between mining and marketing for the first group, and the interconnection between mining and marketing in the case of nonmetallics. Metals and fuels have a guaranteed two-stage market. The guarantee is based on Metal Exchanges, the first stage of trading is that of ore concentrates to the smelters; the second stage is the trade with the metals themselves. The oil industry displays a similar pattern: prices are influenced by the OPEC, the first stage concerns crude oil, the second one with products of refineries. For the nonmetallics this is different. The mine and the (one-stage) market are very close to each other in geographic sense. The earth scientists may often be in close contact with the customer, or, more often with several customers, because there is more than one end-use of the raw material. A guaranteed market is usually missing. Fluorite, mica (large sheets), asbestos, diamond and quartz crystals were in the past considered strategic raw materials.

Typical features of industrial raw materials are the wide price difference between the common and high-grade material (e.g. common crushed limestone costs about 10 USD per ton, ultra pure carbonate filler for paper, plastics, paints and rubber milled to grain in microns costs 50-150 USD per ton). In asbestos varieties, the difference is two orders of magnitude. There is also a great difference between the cost of bulk and bagged raw materials. The prices of industrial minerals and rocks vary within a wide range due to different grades and uses. Because of inflation, their prices in real terms have even shown- after conversion to a constant dollar value- a relative decrease in some commodities.

Unfortunately, mineral resources are not evenly distributed over the globe. International trade corrects this injustice of Mother Nature. Deep-sea trade between industrial countries grows steadily. Talc is shipped from Montana to Belgium, salt from Mexico to Japan, feldspar from Finland to Malaysia, gypsum from Mexico to California, bentonite from Wyoming
to oil rigs all over the world, rutile and ilmenite from Australian placers to TiO₂ – pigment factories on other continents. The demand for materials of unique properties can be satisfied no matter where these materials are found. Kaolin and calcium carbonate can be shipped in form of slurry, unit trains can carry potash from Saskatchewan to the corn belt of the United States or to the port of Vancouver, soda ash is in similar way transported from western US ports, and delivered uncontaminated to glass works on the Pacific Rim, Latin America included. Aggregate from a sea-side quarry in Scotland is exported to Texas.

Most countries either import or export some raw materials for long time. China is not so predictable. Its dynamically growing economy disrupts imports and exports from being net exporter to being a net importer. Similar prospects are also elsewhere in SE Asia, particularly in South Korea, Taiwan, Thailand, Malaysia and the Philippines. It is difficult to predict what is going to happen with its more than 1 mld. inhabitants, and Latin America with almost 600 mill. people when they will fully join the industrial world.

Council for Mutual Economic Aid (COMECON) in Central and Eastern Europe disappeared and new partnerships in international trade emerged: European Union – EU (to 1992 European Economic Community) with 480 mill. customers, Free Trade Area of the Americas (FTAA), with 850 mill. customers. Third main economic centre of the world - SE Asia - has not yet strictly defined its organizational structure as did EU and FTAA. Economic and Social Comission for Asia and the Pacific (ESCAP UN) and Asociacion of SE Asian Nations (ASEAN) have joined the competition not very long ago.

Closest to monopolistic control of the trade were several nonmetallics covering more than 50% world production from a single country: asbestos from Russia in the past, attapulgite – sepiolite from the USA, beryl and bertrandite from the USA, emery from Turkey, fluorspar from China, pyrophyllite from Japan, sillimanite group minerals from Republic of South Africa.

### Table 1

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<tr>
<th>Price Categories</th>
<th>Industrial Minerals</th>
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<tbody>
<tr>
<td>Over 10,000,000:</td>
<td>industrial diamonds</td>
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<tr>
<td>Over 10,000:</td>
<td>iodine, REE</td>
</tr>
<tr>
<td>Over 1,000:</td>
<td>lithium, silicon, quartz crystal</td>
</tr>
<tr>
<td>100 – 1,000:</td>
<td>asbestos, boron, bromine, corundum (and emery), diatomite, dimension stone, garnet, graphite, kyanite, mica, nitrates, potash, rutile, wollastonite, zircon</td>
</tr>
<tr>
<td>10 – 100:</td>
<td>barytes, bauxite, bentonite, (cement), feldspar, fluorspar, ilmenite, kaolin, magnesite, nepheline syenite, olivine, perlite, phosphates, pumice, salt, silica sand, sodium carbonate, sodium sulphate, strontium, sulphur, talc, vermiculite</td>
</tr>
<tr>
<td>1 – 10:</td>
<td>common clay, gypsum, crushed stone, limestone and dolomite, sand and gravel</td>
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Oligopolistic market secures the supply better. Borates from Turkey and USA compete now with raw material from Argentina, Chile and Russia. Australia's diamonds in lamproites have broken the monopoly of DeBeers Consolidated.

Trade with the nonmetallics emphasizes new trends within industries. Decline of the Frasch sulfur is caused by growth of recovered sulfur. Sea water as source of MgO succeeded magnesite in some areas of the world. Natural trona from Wyoming and California is now the main source of soda ash instead of Solvay plants. Precipitated calcium carbonate competes with ground calcium carbonate in many applications.

The share of international trade in world production of individual nonmetalics: more than 80% of production enter the trade with the following nonmetallics: nitratine, iodine, borates; 60-80%: dimension stone, nepheline syenite; 40-60%: bauxite, fluor spar, sulfur, barite, asbestos; 20-40%: perlite, graphite, phosphates, diatomite, mica, vermiculite, kaolin, magnesite, talc.

Marketing study of a nonmetallic project starts if there are possible unexploited reserves of a mineral and/or existing exclusive imports of the same mineral for the local industry, or imports of products based on the mineral in question; and if there is capital available to be invested in prospecting, exploration, and development of any possible deposit, building of a dressing plant, etc.

The first idea gives an impulse for (a) an initial marketing study which should establish a detailed nationwide inventory of known occurrences and deposits in question on the basis of existing written reports, maps, and information of any kind which should be critically assessed. The value of imported minerals or products should be estimated and the possibility of exports to neighbouring countries should be considered.

If such a marketing study results in a positive assessment, stage (b), regional reconnaissance follows which includes inspection of known occurrences in the field to assess their approximate extent, and random sampling intended to determine whether an exploration programme is to be implemented. In this stage mineral occurrences and potentially economic deposits are distinguished, priority areas and exploration targets are outlined. The preliminary analysis of collected samples should indicate if the raw material has the required or expected mineral composition. Should the overall results of stage (b) contained in the first stage feasibility study be positive, stage (c) exploration by grid pitting, trenching and percussion or diamond drilling starts on the deposit, selected as being the most promising. Geological mapping, geochemical studies and geophysical exploration are carried out simultaneously. Bulk samples (tons) are collected for pilot plant experiments. The reserves are calculated assuming that the economic demonstrated reserves will cover the expected production of the mine or quarry for at least 10 years, economic inferred reserves for 15 years more, and hypothetical resources for another 25 years. A second-stage feasibility study will contain results of stage (c), i.e. reserves, composition (content of the useful and harmful component(s), beneficiation characteristics, and suggested utilization of the raw material based on pilot plant experiments; location, access, transport; mineral, water and surface rights; water and energy supply; manpower; mining method, production capacity, protection of the environment, etc.

The second stage feasibility study is followed by drawing up a detailed project (d) of the mine or quarry development of the selected site, including buildings and infrastructure, mechanical and technological design.
Simultaneously with the construction of the processing plant and development of the deposit in stage (e) a detailed marketing study is carried out, to forecast demand, determine the plant capacity, and production costs, etc., including distribution of letters of intent for sales to potential customers in the country and abroad. This study must also make clear the size of the market for the mineral to be produced, the overall financial appraisal of the project, the net profit after deducting the transport, packing and storage costs from the delivery price, the taxes and possible exemptions from them, the competing raw materials, the best range of product grades, the real danger of local government’s intervention in the operation (possible nationalization, ban on export of unprocessed minerals or fixing of floor prices on minerals for export included), the maximum percentage of foreign ownership allowable, ease with which profits can be transferred abroad, etc.

The duration of the individual stages will typically be as follows (in months): a - 2 to 6; b - 4 to 20; c - 6 to 24; d - 3 to 6; e - 24 to 36. All stages from the initial to the debugging of the technical equipment during the start up of the operation can last 3 to 7 years. Geological exploration should continue to allow permanent production planning.

There are several non-economic and non-geological factors influencing the industrial minerals market: OPEC-like cartels influencing a commodity supply (e.g. phosphate in 1974), government-imposed floor prices (e.g., zircon in Australia 1975), government control of mineral exports, or banning of exports of unprocessed minerals, or government participation in mining.

Concluding remark: how reasonable it is to think and act in the terms of marketing and feasibility studies directed to nonmetals? According to P.W.Harben reserves of nonmetals are sufficient for the nearest future only. Most nonmetals in the 21st century will be extracted from yet-to-be discovered deposits.

NEW UTILIZATION OF TRADITIONAL NONMETALLICS AND NEW MATERIALS ON THE BASIS OF NONMETALLICS

The future of the building industry is in application of brick panels or extra large monolithic bricks which are cheaper than concrete panels and have better insulation properties. Hydraulic and dolomitic limes have attracted attention because they have lower firing temperature than the pure limestone. Quite a few rocks can be used as roofing granules in shingle production. Diamond saws cut tiles of decorative stone only 6-9 mm thick.

In energy saving, insulation materials like expanded vermiculite and perlite will be used. Heat insulating mineral fibers will be produced by melting of igneous rocks containing less than 52% of SiO₂, e.g., from basalts. Crushed tourmaline hornfels with 8 % B₂O₃ will be used as a filler in concrete which shields nuclear reactor generating neutron radiation.

Metallurgy can expect supply of alumina and aluminium from non-bauxite sources such as nepheline rocks, alunite, low grade kaolin and clay. The consumption of fluor spar is expected to decline. Beryllium for alloys no longer comes only from beryl in pegmatites but also from bertrandite in tuffs. Silica foundry sand will compete with olivine, zircon, chromite, kyanite and staurolite.

Ceramic industry is looking for fluxing raw materials, usually containing alkalies, which will reduce the firing temperature of ceramic products, thus saving energy. Carbonates will be more used in production of porous wall tiles. High alumina kyanite refractories are
gradually replacing fireclay refractories. Basic oxygen process in steel-making will require basic (magnesite-chromium) firebricks.

The majority of carbonates will still be used in production of cement and lime. Underground mining of limestone is gaining favour in the US because it permits efficient exploitation of reserves covered by thick overburden, allows all year round selective mining, is more environmental friendly than the quarrying, and eventually offers a space for underground storage once the mining operations are completed. In 1989, there were 127 underground mining operations in the US producing 57 mill. tons of limestone (7.5% of the total US limestone output).

From the technological point of view the most progressive application of industrial minerals lies in the field of new materials - composites, special ceramics, ceramic superconductors and optical fibres. The minerals for these new materials should be very pure and treatable, but their deposits or reserves are usually small. The so-called cermets (ceramic-metallic composite materials) are highly refractory being used in aerospace industry. Cermets are occasionally used in combination with whiskers, i.e., thin monocrystalline fibres with remarkable physical properties. A small airplane built of graphite fibres can carry five times its weight. The refrasil (refractory glass fibres on silica basis) is used in tiles covering the fuselage of space shuttle Columbia. It tolerates a temperature of 2800°C for a period of 180 seconds.

Special or technical ceramics employ combination of oxides, nitrides or metals for production of sensors, electronic devices, machine components, nuclear and solar energy materials, bioceramics, catalysts, et cetera. Silicium nitride and carbide and boron carbide will become a part of car engines - the so-called ceramic combustion engines.

Ceramic superconductive materials allow to attain superconductivity at higher temperatures (around 100 K) than in the past (5 K only). Superconductive magnets will enable magnetically levitating trains to travel 500 km per hour. The electricity will be transmitted without any loss due to zero resistance. Electric power generators will double their output. Harnessing of the energy in fusion of hydrogen nuclei by powerful magnetic field may become a reality in not too distant future.

Optical fibres based on silicon or zirconium fluoride speed up connections and save materials in integrated optical systems, telecommunications and lasers (ruby has been also used).

Incredibly pure glass for optical purposes with remarkable characteristics can be produced in near-zero gravity and near-total vacuum abord space ships orbiting the Earth. The same is valid for gallium arsenide semiconductors for electronics, superstrength metal alloys and ultra pure crystals free of defects caused by gravity which can replace conventional silicon chips in the next generation of supercomputers able to make millions of operations per second.

Thin layers of abrasive diamond can synthetically be produced from gaseous hydrocarbons under low pressure in the presence of hydrogen.
1. **new industrial uses** for raw materials already exploited (e.g., graphite fibres, silicon in semiconductors), or because of

2. the **newly discovered** technical and economical importance of hitherto non exploited rocks (e.g., phonolite as fluxing agent, tourmaline hornfels for shielding of reactors), or minerals (e.g., zeolites in agriculture), or

3. **new genetic types** or mineral assemblages (e.g., phosphates and carbonatites as a source of fluorine; non-kimberlite diamond). Finally, the raw materials can be considered unconventional in view of the

4. **substitution** of one raw material for another due to its superior properties or lower price (finely ground calcite instead of washed kaolin as paper filler). Here belongs also the major part of

5. mining, dressing and industrial wastes, formerly dumped, at present increasigly used as raw materials as a result of efforts to develope wasteless technologies.

The factor of time can be introduced in the sphere of unconventional raw materials through classification in 1) unconventional materials sensu stricto, 2) prospective and 3) potential ones.

**Unconventional raw materials** s.s. are already being used in some technologically advanced countries (e.g., non-pegmatite rocks as a fluxing agent in ceramics). The use of **prospective raw materials** in near future can be assumed from trends in technological progress and economic development (e.g., a widespread use of non-bauxite sources of alumina). **Potential raw materials** are not used anywhere in the world nowadays. A prerequisite for their utilization is a considerable progress in technology of mineral processing and abundance of cheap and clean energy, e.g., after resolving the controlled fusion process (perhaps around the year 2050). As an example can be used the extraction of components from aluminosilicate rocks, e.g., granite, of which 100 tons contains 8 t of Al, 5 t Fe, 0,5 t Ti, 32 kg Cr, 15 kg V, 3 kg Cu, 1,8 kg Pb etc.

**New technological processes** require that new raw materials to be found (e.g., the direct reduction of Fe-ores in steel production requires refractories of high quality). Newly discovered properties of minerals and rocks stimulate the search for new uses (e.g., as in the case of wollastonite 50 years ago). New materials lead to innovation or introduction new laboratory methods for identification and measurement (e.g., zeolites 40 years ago).

The spectrum of **industrial minerals and their applications** are endlessly challenging. Can the research fix a "fiber cocktail" that would be close to price of asbestos, potentially carcinogenic? When, if ever, will natural zeolites replace ther synthetic equivalents? Should brucite join other Mg-minerals in the markets? Any chance for fluorine from phosphate containing rocks to reduce fluorspar’s pre-eminence as the only source of fluorine? When gypsum from desulphurization of coal burning power plants or from phosphate processing will substitute for natural gypsum in wallboard production? Will the market for wollastonite expand following its increased output? Will bertrandite in rhyolite tuffs replace pegmatite beryl on the beryllium market? Is there any chance for exploration geologists to discover another trona field like Green River (Wyoming)?

To find answers or to raise new questions makes the field of industrial minerals and rocks extremely complex, difficult to predict, but highly interesting and challenging.
MINING OF NONMETALLICS

The quarrying of the rock is detachment of the material from the rock massif and its breaking. The rock is exploited either underground (rarely used in working non-metallic deposits except for graphite, fluorite, kaolin, refractory claystone, pegmatite, magnesite and a few others) or in surface quarries.

There are two types of quarries: deep pits and shelf quarries in hill slopes. The working faces in both of them are a maximum of 25 m high and the benches are at least 20 m wide; the angle of slope of unconsolidated rocks is 60° at the most and larger in solid rocks. In a quarry it is advantageous to work in the direction of the dip of foliation or planes of separation; otherwise the loosened blocks are liable to slip down along these surfaces which, moreover, may facilitate the inflow of water into the quarry. For the loosening of rocks several blasting methods are used: row- (including the pre-split system), coyot hole-and shock or combined blasting. The row blast is carried out of a row of drill holes 75-200 mm in diameter, which runs parallel to the edge of the quarry face. The drill holes driven parallel to the inclination of the quarry face several meters from the crest and 0.5-1 m below the foot of the wall are filled with explosive (about 100 kg) except for the uppermost 4-5 m, which is stemmed. The row blasting of pre-split system consists of firing a number of small charges near the plastic rock in the footwall which could penetrate the working space, to isolate a safety pillar of small thickness. In this way the deleterious effect on the pillar of the row blast following 140 milliseconds later is ten times smaller. When the blasting is executed from several rows of drill holes, the explosions operate in an upward direction and not into the quarry face. The coyot hole blasts are perfomed by firing several to several tens of tons of explosives from galleries; they are used in well jointed rocks (limestones, columnar basalt) and may loosen up to 40,000 tons of rock. Compact rocks disintegrate into large blocks, which must be blasted anew. The combined blasting utilizes the advantages of both row and coyot hole methods. A shock blast is used where a strong blasting cannot be applied; the rock is only partly loosened and must be further broken by excavators or rippers. Charges are ignited by millisecond priming, i.e. the individual rows or groups of charges are fired with about 20 ms delay each, the interference of shocks after explosion causes the breaking of rock into smaller pieces. Where transmitting or radar station is near the quarry, electric igniters with reduced sensitivity must be used so as to avoid unplanned explosions. The consumption of explosive per one ton of broken stone ranges within tenths of 1kg. The overburden, where thicker than 0.5 m, must be removed selectively. In modern quarries the yearly production reaches 30,000 tons per man.

Soft and poorly cohesive rocks need not be excavated by blasting; they are worked by excavators, scrapers, bulldozers with angledozers, shovels and hydraulic separators (hydromonitors - water guns, particularly on kaolin and glass-sand deposits).

The exploitation procedure affects the quality of the raw material. A selective separation of a good-quality material from the spoil material (innerburden) using, for example, a small digging-wheel excavator which is capable of excavating layers at least 0.5 m thick, can improve the quality of the material by two classes and thus double its value. This holds particularly for ceramic clays and kaolins.
HISTORY OF NONMETALLICS UTILIZATION

Nonmetals were of great importance for mankind as early as the primeval age. The first mineral raw material to be used by man was unquestionably stone. Primitive tools were rough stones, which man used in hunting, for breaking bones or sharpening the ends of branches. In the Old Stone Age, some 200,000 years ago, he learnt to work stone (at first flint, quartzite and hornfels), and to make dyes from them (e.g., ochre, asbolan and chalk). In the Late Stone Age, man made polished and perforated tools from obsidian, amphibolite, pitchstone and others. The first mineral raw material to be worked by mining was flint, which was extracted from the chalk in southern England and in The Netherlands. Flint was dug from pits and adits excavated at several levels, using antler hoes and flint crushers.

Industrial minerals did not lose their importance even when smelting of ores and working of metals had been discovered. With a few exceptions (millstone and hand axes which were last used in the Battle of Hastings in 1066) they were no longer used for making tools, but they served as building materials - as unburnt bricks used for ziggurats in Mesopotamia, burnt bricks in Mohenjodaro on the river Indus, limestone for pyramids in Egypt, calc-silicate marble from Pentelicon for Acropolis in Athens, Carrara marble from Apuan Alps and travertine from Tivoli for buildings in Rome, sandstone and limestone for medieval churches in most of Europe (granite in Brittany and Galicia), volcanic tuff for monuments in Teotihuacan in Peru, granite from the Stone Creek quarry in Connecticut for blocks and slabs for the socle of the Liberty Statue, Columbia University, Smithsonian Museum and Grand Central Station in New York City, and for various skyscrapers.

Most of the building stones were used also by sculptors for statues. Extraordinary stones were used occasionally in Egypt - basalt for statues of pharaoh Menkaure and his wife (4th dynasty), quartzite for colosses of Memnon, and greenschist for the so-called Green Head of a priest (2nd century B.C.).

Stones and minerals were also used as jewels (e.g., turquoise from Sinai during the reign of the 3rd dynasty in Egypt). Glass jewels were made from quartz sand in Egypt already around 3500 BC, (and hollow glass was known in Phoenicia as early as 100 BC). Clay was used for ceramic vessels throughout the ancient world. Faience was manufactured from calcareous clay in Egypt in 2000 BC. Later, clays became important refractory materials employed in smelting of metals. Salt has been an indispensable component of food since immemorial time.

During the Middle Ages, the mode of using industrial minerals did not change substantially. Conditions changed considerably in the modern period, particularly in the 19th and 20th centuries, when new materials were applied in agriculture, chemistry, manufacture of refractory, acid-resistant, filtration and insulating products, and in the ceramic, metallurgical, optical, paper, rubber and foodstuff industries.

ENVIRONMENTAL PROBLEMS CAUSED AND SOLVED BY NONMETALLICS

The environmental impact of mining include the stripping of the overburden and the excavation of a pit, or in the case of underground mining, setting-up of a refuse dump near the shaft or adit, in both cases probably also accompanied by the settling ponds of the concentrator plant, and air pollution. The resolution of conflicts between mining and
environmental protection involves the payment of compensation for the cost of reclaiming the mined-out or damaged area after the operation has ended, and by planting of trees or grass on the surface to prevent erosion.

Most nonmetals are extracted in opencasts and stepped quarries (on the hill slopes), gravel mostly in river beds, valley bottoms or river terraces. The latter, after termination of extraction may form ponds - reservoirs of industrial or drinking water, or places for various water sports. In cases of exploitation of stone and other nonmetals recultivation and revitalization of the area should follow. Natural recultivation of local genofond should be preferred to artificial recultivation by plants alien to the region. Illite and montmorillonite in soils applied in recultivation play positive role in recultivation of brick loam pits and elsewhere.

In general, mineral substances protecting natural environment can be divided into substances protecting (a) the atmosphere, e.g., carbonates removing $\text{SO}_2$ from flue gases, (b) the waters, e.g., expanded perlite with cellulose fibres, silicon oil and vaseline to remove crude oil from water; bentonite and zeolite to absorb metals and organic substances from water, and (c) from the agricultural land. Other minerals reduce energy demands in production lines or cut down the volume of burned coal (e.g. ceramic raw materials with lower firing temperature, heat insulating materials such as expanded perlite or vermiculite, etc.). Industrial minerals also help in storage of communal waste - bentonite is used as a liner, barrier and cover of waste.

The greatest harmful impact on vegetation (acid rain), buildings (crystallization of gypsum in slightly weathered calcite-containing rocks) and human health (bronchitis) has $\text{SO}_2$ in flue gases. About 60 mill. tons of sulfur are produced annually in the world. Pyrite and pyrrhotite at the burning temperature of coal ($1200^\circ\text{C}$) change into magnetite and $\text{SO}_2$ ($3 \text{ FeS}_2 + 8 \text{ O}_2 \rightarrow \text{ Fe}_3\text{O}_4 + 6 \text{ SO}_2$). Addition of carbonate in desulphuration process results in formation of anhydrite and gypsum (the so-called desulphogypsum) which may be used in plaster or wallboard.

Artificial cordierite - produced from special grade kaolin, talc and alumina - is employed as support of special catalyst system removing harmful gazes from exhausts of combustion engines.

Bentonite activated with aluminium sulphate can be used for cleaning of waste waters containing acrilate dispersions on the polymer basis. The contamination is reduced by 93 to 99 % in accordance with the volume of added bentonite (8-16 g/l). The resulting waste can be further used as a fertilizer in agriculture, in animal feed and also in silicate industry.

Bentonite is used also for storage of low-level radioactive waste. All problems related to the storage of all kinds of radioactive waste will be eliminated as soon as a "clean" thermonuclear synthesis of hydrogen nuclei is introduced which may occur on industrial scale some fifty years from now. Harnessing of plasma in this reaction by strong magnetic field is generated by superconductive special ceramics.

Barite can substitute for more expensive ferrosilicon in heavy media liquids used for separation of metals from automobile parts shredded under subzero temperatures. Barite can readily be washed from the recovered metals (Al,Fe,Zn, etc.) by water, whereas ferrosilicon is to be removed magnetically. Barite with 20% of specularite (and less than 3 ppm Cd and 1 ppm Hg) is more cost effective than pure barite in well drilling for oil and gas. Before recession, the production of barite for drilling doubled every 10-20 years.
Industrial minerals will also help in agriculture to feed the rapidly growing population on the Earth. **Zeolite** with 80% of clinoptilolite in a volume of 16 tons per hectare improves the crop of rice by 40%. Cows with 2% of zeolite in feed increased their milk yield by 7% and the use of nutrients in feed almost doubled.

**Bentonites** which can be used in farming (as well as in drilling mud) belong among the alkaline or alkali-calcium type of bentonite (after activation). The application of 20 t of bentonite per hectare in sandy soils, with 10% of its particles under 0.01 mm and with admixture of 1.5% of humus makes the crop per hectare to increase by about 18% in the case of potatoes, by 16% of rice, by 11% of barley and by 9% of maize.

On the other hand, industrial minerals may cause some health problems. **Amphibole asbestos** cause cancer, but chrysotile was by the EPA in 1993 in the US declared to be harmless. The European Union’s proposal to consider all substances with more than 0.1% of crystalline silica as potentially carcinogenic is rather a misunderstanding, because only quartz particles of micron size with razor sharp edges may cause cancer. Such quartz grains usually result from underground drilling in quartz veins.

Elimination of chlorofluorocarbons and halogens through the Montreal protocol (1987) depressed the market of fluorspar. With the prohibition of leaded gasoline, bromine lost his market as ethylene dibromide, but found new applications in fire retardants and drilling muds.

**Conflicts over land use** start with the acquisition of area for exploration and mining, with environmental impact assessment (EIA) of future extraction and processing of the material, project of the quarry, granting license for mining, and result of the whole procedure is according to the attitude of the authorities, the mining company and the public. Seismic tremors caused by **blasting** in the quarry are penalized if they surpass 3 mm/sec. Dust originating by blasting and traffic might be made more tolerable for the inhabitants living close to the quarry, if they are paid an agreed negotiated sum of money each year. A peaceful coexistence with local villagers should be preferred to law suits. The NIMBY attitude (Not In My Back Yard) can be overcome by negotiated benefits for the local community.

**GLOBALIZED WORLD**

Globalization is the result of high-technology communications (400 million people are on internet), low transport charges, trade without frontiers between giant economic blocks (EU, FTAA, SE Asia), free movement of supranational capital in lightning speed transactions between stock exchanges, free movement of labour across frontiers.

**Globalization before and after Kolumbus**

The motive for trade contacts between Phoenicia and Baltic was amber, as was also between Birka, the Viking capital near Stockholm, and Miklagård (Constantinople) or Caspian Sea and the East. Silk Road connected Rome (later Byzantium) with the Far East.

Global contacts (trade, plunder and slave trade) go back to the discovery of America; Mexican silver and Peruvian gold financed the rise to power of Spain, and soon afterwards of England, France and Holland, and were in the background of Rennaissance. Shortly after
Globalization and economic geology

During the World War I and II and the Cold War the opposing parties strove after self-sufficiency in strategic raw materials. The expenditures for exploration, extraction, dressing and further working costs were unimportant. Years of Glory for economic geology were between 1949 and 1977 (or 1989). Reduced fear of the opponent resulted in the diminished role prevalently of metal mining, accompanied by more efficient use of various materials, recycling, substitution, market saturation, shift of customers preferences, growth of influence of the financial sector, with diminishing role of gold until 2000 (A.P. Juhas, G.G. Snow, 2000, SEG Newsletters No. 42). Presently the shareholders of mining enterprises want quick profits that yield increased share price, which requires, among other things, to lower cost of production, exploration and staff. This can be achieved by increasing the output, with the result that the surplus of the raw material in question on market will reduce the price. The "vicious circle" began. Who is going to wait years nowadays for the return of investment capital in mining, if the gamble in the world casino of internet stocks can bring profit in seconds?

Supranational mining corporations

There are 20,000 supranational corporations of all types active in at least three countries (and approximately the same number of nongovernmental civic associations, some of them oppose globalization). The most important mining corporations (non fuel minerals) are: Anglo-American, Rio Tinto Minera SA, TVX, BHP, CVRD (Compania Vale do Rio Doce), Codelco, Phelps Dodge Mining Co., Freeport McMoRan, Noranda, Placer Dome, Newmont, Falconbridge, A.O.

THE FUTURE - SUSTAINABLE DEVELOPMENT OR COLLAPS

Nonmetallics are able to support our civilization - globalized or non-globalized - for all its future. New housing and industrial zones, new motor roads and runways will be built, refractories will help metals to separate metal from ores, crops will be supported by mineral fertilizers, and minerals will be used for materials of the 3rd and all other millennia.

Quite different problem is the outlook of our technical Euro-American civilization as such. It embraced the entire planet owing to high competitiveness, pressure on continuous growth and inventiveness. Competitiveness tends to transform into a desire for power (and money, both mutually interchangeable), and can change to greed.

Greed without scruples and respect to law and moral codex results in corruption, organized crime, activities in the grey zone close to illegality, excessive influence of lobbies of all kinds. This is accompanied by tendency to make oneself visible, especially through media, which can also be expressed in money.
Irrationality of some people, living in technical society based on rational knowledge of science and technology - is another danger for the future world. All aspects from mysteriousness to shamanism in new disguise feed imagination of today people, as if to confirm Tacitus´statement, that Omne ignotum pro magnifico (everything unknown is magnificent). It is undisputable that the spiritual extension of one`s personality beyond elementary being makes life rich on interhuman and moral level, but on higher levels it might be misused to manipulation, as is the case with various sects, superorthodox societies, fundamentalists, some of them with suicidal methods of terror.

The world casino of interconnected stock exchanges with its daily speculative transactions of 1800 bill. USD (and only 50 bill. USD directed to some useful project) make the financial world very vulnerable to superspeculators or hackers. Together with globalization resulting in growth of unemployment (due to increase in productivity of labour) and number of the poor (esp. in the third world) reaching presently 1300 mill. people living on 1 dollar a day, is also a serious reason for instability. Islam will be the refuge of the underpriviliged.

Because of manifold instabilities our present civilization is not capable to create anything sustainable. The critical "point of no return" lies somewhere around the year 2030. Until than the trend can be changed, after that only the struggle with consequences of the greenhouse effect, with overpopulation and local wars trying to change history by changing the state borders, will follow.

Mankind is now in position of Theseus - the Sea-farer, who had to kill the Minotaurus monster, transformed to the appearence of Theseus himself. How painful is to give a thrust into ones own flesh! How difficult is to impose limits on public interests in the name of public interest called survival!

There is still time to prove that there is no such pessimistic law of Nature stating that if the living matter anywhere in the Universe attains such a level of biologic, mental and technological evolution, which is capable of destroying life on its own planet, it does it in due time, even though unwillingly. Four Noble Truths are the key to the survival of mankind: tolerance, compassion, modest way of living, and unselfish attitude to the functioning of World (in our civilization we speak about the performance of "the unknown worker on the vineyard of the Lord").

**BIBLIOGRAPHY**

*Fathers-founders:*

Robert L. Bates (1912-1994), Ohio State University, Columbus
Pavel Mikhailovich Tatarinov (1895-1976), Gorny Institut, Leningrad

*General handbooks:*


Selected regional handbooks:


Periodicals


Annex 1: 7th edition of Industrial Minerals and Rocks will be published in 2005 or 2006 (senior editor most probably Jessica Elzea Kogel) by Society for Mining, Metallurgy and Exploration, Inc., Littleton, Colorado 80123, USA.

Annex 2: It is possible, that Peter W. Harben published (or will publish) another book on nonmetallics. It will be announced in Industrial Minerals magazine (address see Annex 7).


Annex 4: 4th edition was published in 2004 by Metal Bulletin, PLC, Industrial Minerals Division, e-mail: book@indmin.com (price 185 USD).

Annex 5: Last edition of this book was published in Slovak in 1993 by Slovenské pedagogické nakladatelství, Sasinkova 5, 815 60 Bratislava, Slovensko.

Annex 6: The 4th edition might have been published after 1987 by American Geological Institute, 4220 King, Alexandria, 22302, Va., USA.

Annex 7: Industrial Minerals magazine (published since 1967) can be ordered on address: Industrial Minerals, UK sales, Park House, 3 Park Terrace, Worcester Park, Surrey KT4 7HY, UK; e-mail: ads@indmin.com