

Industrial minerals and rocks for high technology products

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TRENDS IN THE UTILIZATION OF MINERALS AND ROCKS

Minerals and rocks have long been a part of human life, almost as long as man has existed. It is difficult to say which mineral, metal or rock was first used. Furthermore, the recognition of usefulness was soon followed by the recognition of the properties of the surrounding materials. Clay is sticky and mouldable, firestone is hard and its splinters are sharp, gold is shiny and malleable, rocks are workable and some minerals are even tasty. From such fragments of experience, it was only a small step to collect these materials, trade and experiment with them. That was the beginning of technology. Over the years, the usage of minerals and rocks has undergone numerous innovations and many inventions have been found. At certain periods, usually associated with wars or welfare, the rate of technical development has been accelerated.

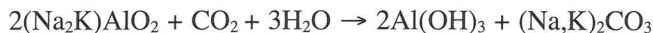
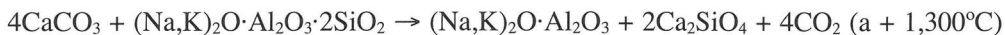
Technology does not expand linearly but in 'jumps'. At present, these jumps are more frequent. In the past, such jumps have occurred sporadically, being associated with the movement of tribes. When meeting and/or fighting with other groups, technical achievements were often transmitted. We could say that high technology and high technology products were already being manufactured in ancient times. On the other hand, both wars and welfare (indolence) periods have also destroyed the technological heritage and caused the slow down or extinction of technology so that technical skill fell into oblivion. Because in the past, the application of natural materials was based only on an empiric approach, the progress was rather slow. Nowadays, the application of minerals and rocks is based on a scientific background. The progress of science and technology is driven by a multidisciplinary approach expanding the comprehensive knowledge on materials. Growing information on materials and its fast and easy transmission together with the growing family of scientists and engineers makes the rate of development exponential.

Recently, new products from surrounding materials are being engineered daily. However, the utilization of these industrial minerals changes. Instead of their direct use as industrial minerals, they have become the starter material for the production of pure metals and alloys (e.g. Be, Ce, Mg, Si, [BeCu], [FeSi], [ThMg], [BNdFe]), oxides (e.g. Al₂O₃, CaO, Fe₂O₃, MgO, REO, TiO₂, ThO₂) or other pure compounds and minerals (e.g. K₂CO₃, LiCO₃, Na₂CO₃, SiC, cordierite, cryolite, hectorite, periclase; wollastonite), some even in modified species (e.g. garnet, hydrotacites, perovskite, spinel). Many of the products made from industrial minerals and rocks do not always occur as natural phases. New materials and devices are complex in as far inorganic and organic compounds are mutually interrelated.

CRITERIA FOR HIGH TECHNOLOGY (HT) AND HIGH TECHNOLOGY PRODUCTS (HTP)

High technology (HT) differs from conventional technology by the distinct improvement of efficiency and the product quality. This is accentuated by numerous adjectives and adjacent expressions such as. "high purity", "stronger", "more durable", "high duty or high performance" etc. in product characteristics. Also, extraordinary properties of the material are specified like, "nano-sized", "fibrous", "resistant", "rechargeable" etc). The manufacturing of HTP should also be simple and faster, without health and environmental hazard. Therefore HT must be clean, without or minimum discharged rejects and waste. Finally, the recycling possibility of used products should also be available. All of this, is associated with cost increase. Nevertheless, the price of HTP is reasonable, adequate to better quality and longer life.

The objective of the material research is **clean technology**. Nepheline syenite technology can serve as an example. Nepheline syenite is a rock, rich in alumina, sodium and potassium. Sintering of ground nepheline syenite with limestone results in the forming of water-soluble sodium and potassium aluminates. These can be extracted and subsequently used for the production of sodium and potassium carbonates (Na,K)₂CO₃ and aluminum hydroxide. The insoluble residue consists mainly of di-calcium silicate and is a suitable material for the manufacturing of cement. Such technology produces no waste, as shown by the following reactions:



Other examples of modern coal technology are synfuel manufacturing and coal gasification. Beside gas production, modern coal gasification comprises of gas cleaning and separation of valuable by-products such as sulphur and ashes. The process takes place in a surface plant, associated with a power-generation plant that uses the clean gas produced. Sulphurous oxides are converted in native sulphur. Separated noncombustible ashes are melted in glassy slag, crushed after cooling and used as aggregate for construction materials, mainly in bituminous concrete. Only fluorine and nitrogen are critical. The majority of fluorine remains incorporated in the glass. Flue gas from the gasification then contains, with only fluorine, water vapor, CO₂ and NO_x remaining. In comparison with older coal

power-generation plants, air pollution is significantly reduced. A few years ago, a modern gasification pilot plant was tested in the Netherlands.

Recently, the possibility of underground coal gasification has also been tested. During the underground coal gasification (UCG), coal is gasified underground in a cavity in the buried coal seam surrounded by the host rocks. Gas quality is controlled by the injection of oxygen or oxygen-enriched air and steam. Solid impurities (ashes and thermally affected rocks) and the majority of hazardous gasses and compounds remain in underground gasifier, which is later cemented.

Advanced technologies in the past

Many ancient monuments and products witnessed the existence of advanced technologies in the past. There are several admirable old temples, castles and ancient cities and monuments that were constructed from blocks of rocks often bigger than 100 m³/block. These blocks were extracted and transported from quarries for distances of many kilometers. That would be a tricky job for present day constructors and engineers. The blocks were shaped with the highest precision and put together without any mortar. The transport and lifting of such structural elements to the top of columns and monuments, indicate the respectable skill of ancient constructors.

The amounts of materials applied by the ancient constructors are also considerable. Large cities like Ur, Nineveh, Babylon and many others were built from billions of light weight porous bricks. The porosity was achieved by the utilization of a mixture of clay and grass. The burning grass provided a low-temperature firing and the resulting pores gave the brick its thermal insulation. The bricks were then bound together by bitumen and reinforced with straw. No wonder, that walls built from such bricks survived thousands of years. The archeological artifacts, tools, weapons, jewels and other things are also to be admired.

The ancient products and how they were made remain a mystery. Nowadays, many laboratories are trying to simulate ancient technology and achieve the same results. However, these trials not always are successful. Trials to prepare steel of the famous "Damascene" quality are well known. The secret of Damascene steel is in its laminated structure with iron and cementite (Fe-carbide) lamellae. But how these materials were prepared is still not completely understood. There were trials of long hammering of glowing iron lamellae with intercalated grass. Another, rather cruel procedure for the carbonation of steel (generation of FeC layers) human or animal blood was also used, where the process required certain temperatures. These was estimated according to the colour of the sunset. When the sun was the required colour, the slaves were killed by a glowing sword at the moment when the hot iron penetrating the body, was the same colour of the sun. The blood supplied the carbon and iron in laminas of cementite after immediate, intense hammering. Is it a story or the truth? The perfect damascene steel has never been imitated.

Exhibitions and/or workshops dealing with ancient technology are organized worldwide. The demonstration of the manufacturing of flint arrowheads, ceramics, jewellery, metallurgy and other processes are very popular. The history of the technology shows that inventiveness and skills of our predecessors was great. Patient observation, deliberate analysis and trials without haste, drove mankind to new frontiers.

HIGH TECHNOLOGIES AND NEW TRENDS

The achievements of science and technology increase exponentially. What mankind achieves in one decade is not comparable to another. Modern material science continuously deepens theoretical basis and advanced technologies and procedures for HTP manufacturing is reflected in the multianalytical approach. Many natural industrial minerals do not meet the new quality requirements nor are available in sufficient amounts. Therefore, mineral technology, together with chemical technology, helps to purify the material and/or synthesize a material of desired quality and quantity. Obviously, all associated processing affects the cost of the industrial minerals. That is the case of cryolite, cordierite, corundum, diamonds, garnets, graphite, hectorite, perovskite, REE, rutile, soda ash, thenardite, wollastonite, zeolites and many others. HT often calls for materials that do not occur in nature. These materials have similar structures, but differ in chemical composition and structural perfection. A variety of artificial, chemically modified minerals, such as organoclays, hydrotalcites, garnets, perovskites, spinels demonstrate this strand of research and development of non-conventional ceramics, catalysts, semiconductors, and, super conducting materials.

The mechanical and chemical modification of mineral phases became an important activity of modern technology. The upgrading comprises of the incorporation of unusual elements in the structure by replacing the normally present elements or adding some new elements in inner pores (e.g. in case of pillared clays). Minerals are often prepared, that do not occur in nature such as silicon carbide, Al-chalcopyrite CuAlS_2 (synthesized by means of gas transport procedure), or super-conductive YBaCu-oxide.

The development of the new materials with engineered mechanical properties is simulated by the development of particle technology. Many other advanced technologies have drastically changed worldwide industrial development. Several years ago, Skylab experiments initiated a new époque of material science. These experiments brought forth new ideas on the material preparation and synthesis of materials with extraordinary properties and behaviour.

The application of plasma technology, lasers and gyrotron firing, significantly affected the firing and melting processes in ceramics and metallurgy. Plasma technology accelerates the firing process, coating and ceramic film manufacturing especially for high refractory materials and insulators. It is also possible to mention other technologies that have had a revolutionary impact on new materials. For instance, spinning technology and producing fibres and whiskers of any solid material, affects the manufacturing of insulators (e.g. glass wool and rockwool), superconductors, and, the strengthening of materials by fibres (e.g. graphite, glass, cement, plastics), mainly communication systems which use glass fibres.

The manufacturing of HTP is the utmost objective of material science and advanced technology is the important prerequisite to do it. Research and development are closely interrelated. Innovative technology usually goes ahead of manufacturing. Nevertheless, manufacturers also often initiate and contribute to the technology upgrade.

Scientists are leaving the micro-scale technology of chips and other electronic devises. About twenty five years ago, the new nano-science and nano-technology announced the ambitious plans of nano-fabrication of structures smaller than 100 nanometers (Scientific American 2001). Expected fields of application cover catalysis, data storage, medicine, the manufacture of raw materials and enhancement of material properties. These, will be later

governed by a complex combination of classical physics and quantum mechanics. Thus, scientists and engineers will have to think differently.

COMPLEX TECHNOLOGY - HIGHER PRICES

Research and development of HTP is complex and costly, regarding all involved procedures from preparation of materials up to the manufacturing of products. Prices of HTP may be higher but must be justified by a longer life and quality. The relevant costs of purification and synthesis procedures and also sophisticated instrumentation needed for its manufacture are included in the price. In Table 1, some prices of industrial minerals in their natural form are listed (as lumps or concentrate), others as processed products or final products. Examples of prices of some industrial minerals needed for HT products.

TABLE 1
COMPARISON OF PRICES OF SOME INDUSTRIAL MINERALS AND PRODUCTS

Industrial high quality diamonds	500 000 000
Silicon (single crystal wafers)	10 000 000
Lumbered quartz (>99.99 SiO ₂)	140 000
Quartz sand	15
Silicon carbide (for engineering ceramics)	27 000
Silicon carbide (for abrasives)	1 400
Silicon carbide (for refractory bricks)	750
Petalite (>7,5% Li ₂ O)	400
Lithium chloride (anhydrous)	10 630
Alumina	5 000
Carbon fibres	4 000
Bastnasite concentrate (REO 70% leached)	2 300
Monazite concentrate (min. 55% REO)	700
Praseodymium 96%	39 000
Europium	1 000 000
Thulium 99,9%	3 600 000
Graphite (Sri Lanka)	820
Graphite (Swiss)	2 230
Glass fibres	1 500
Glass	750
Cement	70

Notes: Prices in USD/t (based on data in 1990). Prices vary substantially.

The table also shows the differences between concentrate, half product and final product. Within the high prices, we should see the costs of treatment and processing used in the fulfilment the desired quality requirements.

INDUSTRIAL MINERALS AND ENERGY

The application and involvement of industrial minerals in energy matters have a high priority. Some industrial minerals are directly and indirectly associated with energy generation, energy conservation and energy saving (Kühnel, 2003): Years ago, the reaction heat from the oxidation of metals (namely aluminum from Al-scrap) was applied. It improves the efficiency of melting of metals and the homogenization of alloys. Thermo-chemical heat from aluminum oxidation allows high operation temperatures ($> 2000^{\circ}\text{C}$) that are necessary for the homogenization of ferroalloys like (FeCr), (FeMn), (FeMo), (FeSi), (FeV), (FeW) and others. Reaction heat is about fourfold that of cokes. However, the oxidation of metals and subsequent heating effect begins with the oxidation reaction, usually at higher temperature. Slag from the oven is rich in corundum and spinels. After grinding, such slag may find an application as an effective abrasive.

There are other different elements also supplying high reaction heat or oxidation. The highest reaction heat is associated with praseodymium oxidation into Pr_6O_{11} and vanadium; these values are fourteen and ten times respectively higher than that of cokes. The oxidation reaction of some elements is spontaneous and explosive (e.g. H_2 and Mg). Hydrogen has the brightest future as the future fuel for energy generation and for cars. However, because of the explosive reaction with oxygen, the most critical factor is the guarantee of the safety of the fuel cells.

Fuel cells are devices that convert the chemical energy of a fuel directly into electricity by an electrochemical process. In such fuel cells, fuel and oxygen are supplied to the electrodes. In comparison, the electrodes in a fuel cell do not change. The development of fuel cells started in 1930, and was based on hydrogen and oxygen and two inert electrodes. Nowadays, few types of fuel cells are developed and tested on different scales. These new types of fuel cells use different fuels e.g. carbon monoxide, hydrazine, methylalcohol or some hydrocarbons. So-called alkaline fuel cells use electrodes such as steel, graphite or ceramics, new electrolytes include proton-exchanged membrane, phosphoric acid, molten carbonate and solid oxide ceramics. Platinum, nickel and synthetic perovskite are applied as a catalyst in these cells. The operation temperature of these cells is in the range of $80\text{--}1000^{\circ}\text{C}$. The future of fuel cells is bright and the competitiveness of fuel cells with high energy costs, increases.

In the construction of the new generation of cars, more industrial minerals are involved. They are incorporated into the engines, chassis, electronics, windows, tyres, batteries and other parts. The engine may become ceramic, chassis reinforced by fibers, tyres filled with nano-sized carbon, windows shock- or bullet-proof, batteries from a metal hydride fuel cell and in the electronics, dozens of micro-devices for engine control may be applied. Behind the excellent services of all these car parts industrial minerals are hidden.

The use of hydrogen as a fuel is justified. Burns et al. (2002) calls the 21st century as the “hydrogen society”, regarding the revolutionary progress of hydrogen cells for cars. The transition from conventional fuels to hydrogen has already begun and several dozens of new generation hybrid vehicle models already compete successfully with cars of the old generation. The prototypes are permanently innovated. This development goes ahead rapidly. However, there are always some remaining problems. The introduction of hydrogen fuel widens the applications of minerals and products

TRADITIONAL AND MODERN CERAMICS

Through time, ceramics and ceramic technology underwent significant changes from ancient pottery to the new generation of HTP, including the invention of superconductors. By means of the traditional ceramic technology, only clay-based bodies are produced. Modern ceramics also deals with other than clay materials and includes composites and cermets. Besides bodies, the HT ceramics also include coatings and powders. In composites, two or more non-metallic phases in an intimate mixtures form materials with specific, desired structures (e.g. multilayers) and properties (e.g. low- & high density). In cermets mixtures, metallic phases are also used.

Traditional ceramics (BODIES only) High technology ceramics

Permeable:

- Pottery
- Fire bricks
- Faenzes
- Crockery (e.g. Gubio, Delft's blue)
- Bricks & roofing tiles

Impermeable:

- Biscuit
- Soft porcelain
- Hard porcelain
- Gres
- Wedgewood

- POWDERS
- COATINGS
- BODIES
- COMPOSITES from:
oxides, carbides, nitrides, borides
silicides
carbosilicides, carbonitrides,
carbaborides
boronitrides, oxynitrides, sulfides
- CERMETS
glass fibers,
metal fibres, whiskers, carbon fibres

HT ceramics is finding wide application in new branches of ceramics such as bioceramics (mainly purest α -alumina), electroceramics, magnetoceramics, piezoelectric and electrooptic ceramics. Artificial joints and bones made from the purest corundum (α - Al_2O_3), belong to bioceramic HTP. Composite materials for dental ceramics and also porous bio-filters and others are produced by HTP too.

The rapid development of electroceramics took place in last decades of the 20th century. The main objectives, were better quality and possible miniaturization. Great attention was paid to insulators where five major properties played a role, namely, dielectric constant (k'), electrical resistivity (ρ), dissipation factor (δ), dielectric strength (DS) and dielectric loss factor (k''). Porcelain, zircon, talc, forsterite, cordierite, alumina, spinel, mullite, MgO, BeO, ZrO₂, ThO₂, HfO₂, ceria, spodumen, boron nitride, silicon nitride, composite pyroceram, mica, glass and quartz glass are used as good ceramic insulators.

For insulators, there are important thermal properties as well as dielectric properties. Excellent services provide talc, cordierite, LiAl silicates, silicon nitride and quartz glass. These have the optimum thermal conductivity, thermal coefficient of expansion, tensile strength, compressive strength and thermal shock resistance. Ceramic insulators are also made as thick and thin films, partly crystalline. These are either glassy or made from porcelain.

Some industrial minerals found an application in the manufacturing of ceramic **capacitors**. The enormous expansion of integrated circuits led to a phenomenal growth of the production

of ceramic capacitors. The mentioned production is 7.3 billion ceramic capacitors in the year 1981 of a value of nearly 500 million USD. The critical electrical properties such as dielectric constant, dissipation factor, insulation resistance and temperature dependences have been an important function in the storage of energy. Porcelain and talc, rutile and barium titanite belong to the basic ceramic materials.

Piezoelectricity, known about since 1880, is based on monocrystals of a certain symmetry. Quartz crystal is a suitable example. An electric charge is generated by pressure. Certain crystalline compounds called electronic ceramics, ferroelectrics, piezoelectrics and electrooptics also show piezoelectric properties. Raw materials used for manufacturing piezoelectric and electrooptic ceramics devices comprise of stoichiometric compounds of solid solutions, including barium titanite, lead zirconate titanite, lead niobate, bismuth titanite, sodium potassium niobate and lead titanite. One of the most successful example of the application of piezoelectric ceramics is the manufacturing of mould speakers, tweeters and sounders, massively applied in mobile phones, computers and other devices. The quality requirements for raw material used, are high and besides the chemical criteria, the structure of powders is also critical. Strict procedures for preparation of raw materials are prescribed.

Magnetoceramics represents the new generation of magnetic materials. The last metallic magnet was a samarium-cobalt alloy. A new generation of magnetic materials are oxidic compounds, the so-called ferrites. The ferro- and ferri-magnetic materials have a 'hysteresis effect'. Ferrites are all oxidic compounds with preponderant Fe_2O_3 and they exhibit a spontaneous magnetic induction in the absence of an external magnetic field. There are several groups of ferrites: spinel ferrites (e.g. spinels AB_2O_4) where B is a transition metal oxide, garnets ($5 \text{Fe}_2\text{O}_3 : 3\text{Me}_2\text{O}_3$) where Me is a REE (e.g. $\text{Y}_3\text{Fe}_5\text{O}_{12}$ signed YIG) and magnetoplumbite ($6 \text{Fe}_2\text{O}_3 : 1\text{Me}_2\text{O}_3$) where Me is Ba, Ca, Sr. Third type is hexagonal ferrite – compounds from the field of ternary system $\text{BaO-MeO-Fe}_2\text{O}_3$ with defined ratios ($\text{BaO-MeO/Fe}_2\text{O}_3$). Also of great technological interest is the hexagonal compound $\text{BaFe}_{12}\text{O}_{19}$, that is isostructural with the naturally occurring magnetoplumbite. Ferrites should have high purity. They are synthesized from raw materials that are prepared as powders. Homogenization firing and hot pressing is important. In the past, ferrites found wide applications in low-level transformers, inductors, telecommunication filters and ceramic sensors. Recently, some nitrides (e.g. $\text{Sm}_2\text{Fe}_{17} \text{N}_3$) and borides (Fe-Nd-B)-compounds have been found to be very strongly magnetic.

In the early years of the 20th century, the first liquid helium was prepared. The search of superconductivity was then instantly begun. After 100 years of research, numerous super conductive substances were found. Mercury was first was measured and registered as a superconductor. Later, lead and niobium, niobium nitride and triniobium tin and triniobium germanium were also found to be super conductive at very low temperatures of around 20 degrees of Kelvin temperature (°K) Research of superconductivity has proceeded toward super conductive materials working at a higher Kelvin temperature. In eighties of the 20th century, a great number of compounds were discovered, such as Y-Ba-Cu-oxide, Bi-Sr-Ca-Cu-oxide, Tl-Ba-Ca-Cu-oxide and Hg-Ba-Ca-Cu-oxide. These compounds are operational at 100 to 140 °K. In 2001, the superconductivity of magnesium diboride (MgB_2) was described by Canfield and Bud'ko (2005). The working temperature of that ceramic material is 30-40°K.

ADVANCED TECHNOLOGY AND PRODUCTS IN OTHER INDUSTRIES

As regards the examples of applications of industrial minerals in energy matters and on booming modern ceramics we saw the progress of high technology and the new HTP. The HT does not always lead to a new material or product. Its feedback is focused also on the innovation of existing materials and products and promotes the re-use of recycled materials. It would be impossible to complete the list of all the industries where the HT helps to improve the quality of the products. Therefore, a brief survey of several innovative trends in manufacturing construction materials follows here:

Products	Involved industrial minerals
Construction materials	Recycled concrete, residues after combusted garbage plastics, organic matter
Artificial stones and prefabricates	Coloured rocks, concrete, pigments
Artificial breccias, terrazzo	Rock fragments, concrete, plastics
Sand-lime bricks (artificial)	Sand, lime, tobermorite
Panels	Gypsum, organic matter (e.g. animal hair)
Lightweight materials	Porous products
Porous bricks	Clay and organic matter, coal washing residues
Hollow bricks	Clay
Ytong (aerated concrete)	Sand, fly ash, lime, aluminum, tobermorite
Expanded shale	Shale, slate
Expanded perlite	Perlite, pumice, scoria, volcanic ashes
Glass- and rock-wool	Basalt, dolomite, coke
Thermal and sound insulators	Vermiculite, diatomite
Barriers for sealing waste depositories	Bentonite, sand, plastic
Clays and zeolite	Clay minerals, natural and modified
Glass (mainly sheet glass)	Sand, limestone, recycled glass, dolomite,
Safety glass (against radiation)	feldspar, nepheline syenite, soda ash, Na-sulphate,
Shock proof and bullet proof	borates, Sr and Pb compounds etc.
Smart glass *)	Li-compounds, W-compounds,

*) Smart glass, also called 'private glass' (electrochromic window and liquid crystal window) is new HTP (Scientific American 2005). It is a composite with embedded conductive coatings, Li-storage and tungsten oxide coatings between two sheets of glass. When unpowered, all layers are transparent. Applied voltage converts tungsten oxide in tungsten bronze that produces a tint and darkening. Liquid crystal intercalation with an adhesive layer, thin film and conductive coating between two glass sheets also control by power translucency or transparency caused by orientation of crystals. Prices of such glasses are 10-15 times higher than normal sheet glass.

Conventionally, there are five major requirements on construction materials: availability, strength, beauty, workability and durability. Because of the need of environmental care, difficulties with recent mining and quarrying permits, attention is now paid to recycled materials, like old mining rejects, slags from metallurgical plants, rubble from the demolition

of old buildings and residues left after incinerating garbage. The majority of construction materials made from recycled materials generally meet the quality requirement, but in the minds of constructors and users of construction materials, there remains a certain distrust of these materials and some psychological aversion, taking into account the origin of the material, bearing in mind that that brick or slab was once garbage or waste from a hospital. Nevertheless, the use of recycled, not hazardous, rejected materials and residues of any kind for construction purposes, is a creditable activity that also deserves to be called the product of advanced technology.

Finally, let us have a look on the historical role of clays and clay minerals. Their common availability and extraordinary properties made from clays of the first raw material intensively exploited by the human race. The ancient artifacts, construction materials, pottery, tablets, tools and artistic objects help to reconstruct the life in ancient settlements and recognize the technical skills of men. The artifacts show the permanent upgrading knowledge on clay in time. Nowadays, the list of clay applications is endless. Few decades ago, the growing interest in clays resulted in formulation of Clay Science. Recently published Handbook of Clay Science (Editors Bergaya et al. 2005) covers majority of clay applications in our daily life. Clays also have their HT and HTP. To the important HT belong clay modification and engineering of the barriers for waste depositories and to HTP belong catalysts, organoclay-polymer nanocomposites.

CLOSING REMARKS

The full potential of industrial rocks and minerals is not yet fully understood. There will be more new applications in the future. These may be as a result from a combination with other raw materials. In mixtures, minerals supply the desirable property and/or service to the new product. With its integration with metals, fuels, plastics and organic material is the future. Consequently, a further characterization of mixtures and composites is needed.

More attention should be paid to organic materials, plastics and recycled materials. Good management of waste is the primary objective of environmental care. Any reworking of waste and even its partial use should not produce more new hazardous waste.

In the future, industrial rocks and minerals will remain the leading raw materials in the manufacturing of new products. The proportion between direct and indirect application will not be changed. The direct use of natural materials will increase because of large scale applications, mainly as construction materials. The indirect applications will comprise of a smaller, but much more versatile fraction. Industrial minerals and rocks will be more “ores” for chemical technology used for the synthesis of certain elements and compounds that do not occur as natural sources.

Certain minerals will become strategic; the demand will be higher and prices will increase too. This could be the case of the boron compounds, lithium, and rare earth elements.

High technology is a prerequisite of high technology products. The value of such products is not only expressed by price. Equally important are safety and general benefit. Hopefully, the various selected examples mentioned will widen the readers’ angel of vision of importance of natural raw materials and their future.

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