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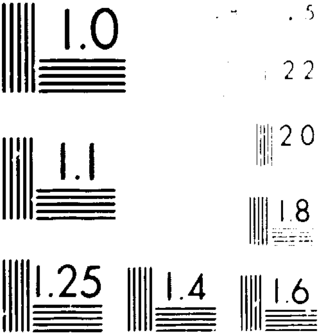
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GEOLOGICAL RESEARCHES OF NON-METALLIC RAW MATERIALS AND NATURAL CIVIL ENGINEERING MATERIALS**

by

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INTRODUCTION

Non-metallic mineral raw materials comprise a large group of various and varied minerals and rocks in the earth's crust. They are applied in many branches of industry or are used in their natural form in the building construction industry, agriculture, the crafts and so on. By their chemical composition they are mostly compounds of Si, Al, Mg, Ca, Na, Cl, F, P, K, C, O and others, and they appear in the form of alumo-silicates, silicates, carbonates, oxides, chlorides, phosphates and sulphates. The main property of all these raw materials is that, as a rule, metal products are not obtained from them, the exceptions are few.

This does not mean to say however, that non-metallic minerals are of second-class importance for the national economy: on the contrary! Available data indicate that non-metallic raw materials are widely used particularly in the developed countries so that the degree of their utilization can be taken as an indicator of the level of development of a country. In fact, the development of the metal industry itself would be inconceivable without the application of non-metallic raw materials (smelting furnances; dams for hydro-power stations, etc.).

The systematization and classification of non-metallic minerals is complex and varied. They are sometimes classified according to their application (technological classification) and sometimes according to their origin (geological classification); in each case there are a number of sub-divisions as well. In any case, the position of many raw materials in a classification table is not exclusive or difinite. Thus, for instance, a certain raw material (of the same origin) may be applied in the same form in various industries or other branches of the economy; there are also cases of a raw materials of identical technological properties having been formed in different geological periods.

By their application, non-metallic raw materials are usually divided into three groups:

A - industrial raw materials;*)

3 - raw materials for the building construction;

C - semi-precious and precious stones.

The non-metallic mineral raw materials mainly applied in industry include:

Refractory and brick clays, quartz and cement raw materials, magnesite, talc, asbestos, salts, sulphor, gypsum, phosphorite, apatite, flourite, diatomite,mica, perlite and others.

The non-metallic raw materials applied in the building construction directly include:

- Rocks of sedimentary origin gravel and sand, tuffites sandstone and slate limestone and its metamorphic products - marbles etc.,
- Rocks of magmatic origin: granite, diabases, gabbros, periodite,dacito-andesite, basalt, tuff etc.,

The semi precious and precious stones are:

- Technical stones: diamonds, corundums, quartz, etc;
- Decorative opals, chalcedonies, agates, etc;
- Precious stones: diamonds, emeralds, topazes, etc.

The second principle on which classifications are based is indispensable for geological research. It consists of the conditions under which a certain raw material was created (environment, time, climate, endodynamic and endothermal agents etc.). For the raw materials to be found on the territory of Yugoslavia, we have proposed a classification based on the geological complexes in which individual non-metallic minerals frequently (not exclusively!) occur. In this way three groups are obtained. They are:

1. Non-metallic raw materials connected with the tertiary complex;

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*) These include materials used in the coustruction industry such as cement, ceramics, heat-resistant and thermo-insulation parts for construction, etc. as well as the industrial processing of raw materials for agriculture.

2. Non-metallic raw materials connected with the Mesozoic and particularly the ophiolite complex (2b);

3. Non-metallic minerals connected with the metamorphic complex (crystalline).

In continuation of this paper we shall be examining these groups of raw materials, exploration methods, chances of discovering new deposits and expanding their range.

NON-METALLIC MINERAL RAW MATERIALS IN YUGOSLAVIA

About 60 different kinds of non-metallic mineral raw materials have been identified in the world today. On the territory of Yugoslavia 45 different kinds have been discovered but only 35 are being expoloited (or have been explored sufficiently for exploitation to begin). The latest explorations has, on the one hand, increased the deposits of the raw materials that are being exploited and, on the other, increased the total number of different non-metallic raw materials discovered. A survey of these raw materials is provided in Table 1. Space does not permit a detailed analysis of each of them, nor is that the purpose of this paper, but we shall refer to the principal characteristics of each of the mentioned groups according to their geological complexes.

NON-METALLIC RAW MATERIALS OF THE TERTIARY COMPLEX

The most widespread among these and the most abundant in terms of deposits are various clays and sands. Yugoslavia's virtually total ceramics and glass industries are based on them. They are furthermore applied in many other branches of industry. For instance, various types of clays are used in the industry of refractory materials, the chemical industry and others. Quartz sand is indispensable for castings in the chemical industry and in building construction. Among clays, brick clay deserves special mention as one of the basic materials for the construction industry. It is interesting to note that all these raw materials are frequently found together, either in the same deposit or one below the other or one alongside the other.

Rock formations from the Tertiary are the principal carriers of some other important non-metallic raw materials such as those for the cement industry (which again means building construction) cement marl and tuffs; for the chemical industry - bentonites, diatomaceius soil; the industry of refractory materials - sedimentary magnesite etc. Some rocks dating from the tertiary sedimentary complex are also used in the construction industry such as: gravel and sand (with the exception of the alluvium - the main source) limestone and, for ornamental purposes, multi--coloured sandstone and marbled onyx.

Magmatic formations of the Tertiary complex constitute an important source of construction stone. They are the source of large quantities of broken stone aggregate for roads, stone cubes for the roadway and the kerbs, but also partly of ornamental construction stone. Their basic varieties - basalt and basalt-andesite may also be applied in petrurgy (cast tubes etc.). Finally, the occurence of certain semiprecious stones (amethysts, opals) is considered to be connected with the effect of hydratic solutions originating from tertiary volcanism.

NON-METALLIC RAW MATERIALS OF THE MESOZOIC COMPLEX

In this complex there are no brick clays, gravels or sands and much less of the other non-metallic raw materials characteristic of the tertiary complex. There are however, rich deposits of other non-metallic mineral raw materials which are predominantly used in the construction industry.

Among the sedimentary formations of the Mesozoic, particular attention should be devoted to limestones and their multifold application in construction: they are the main source of lime but also of considerable quantities of construction stone (concrete aggregate, broken stone for road and rail embankments etc.); some species are used as ornamental material for facades or inside walls. Dolomites are not so widely used in building construction but far more in the chemical industry and they are an essential material for magnesite production using sea water. The complex also includes fire clays from the Lias and the presence of good quality quartz raw materials can also be expected. It should be noted that within this complex singificant deposits have been found of bentonite (in connection with porphyritic tuffs), some barite, white bauxite, etc.

b. Magmatic formations of this complex contain some very important non-metallic raw materials. The best quality magnesite is to be found in perioditite bodies of the Jurassic and some dunites from these bodies are used in the refractory industry; in some areas the perioditites carry chrysotile-asbestos and occasionally talc. The diabases belonging to the same magmatic complex provide material for mineral thermal insulation (in some regions that is its principal use) but it is also used in construction (provides good broken stone for roads) while their intrusive equivalents are mainly used as architectural ornamental stone (gabbros).

NON-METALLIC RAW MATERIALS OF THE METAMORPHIC COMPLEX

This complex embraces non-metals in Paleozoic formations and non-metals in the crystalline basement of the Precambrian. The Paleozoic formations also include non-metallic raw materials like those from the Mesozoic, particularly construction stone of both sedimentary and magmatic origin (limestones and marbles granites, diabases, gabbros) as well as certain non-metallic raw materials which are not to be found in more recent formations: roofing slate for instance, graphite, phosphorite etc. and in carbonatic rocks in some regions crystalline magnesite can also be expected.

The crystalline fundament has a very specific content of non-metallic raw materials. It is the main source of feldspar and mica (in pegmatite bodies) and noteworthy phenomena of precoious stones (beryl). There are also still inadequately explored deposits of crystalline magnesite, quartz veins and other invaluable mineral species. Some of them were not known to exist at all and it is only in the past few years that their presence has been established (vermiculites).

PRINCIPLES OF EXPLORATION

All ore deposits, including deposits of non-metallic raw materials have in different period been discovered in different ways. At times, their discovery could be attributed to a set of circumstances or chance and their application depended on the needs and experiences of the local population and their craftsmen (bricklaying, pottery, the use of stone in construction work, etc.). The days when complete laymen, chepards in most cases, used to discover minerals belong to the distant past.

With the development of industry and the modernization of building construction there has been a growing demand for non-metallic minerals in terms of types, quantities and grades so that multi-disciplinary teams of geologists of various specialties have to be engaged in procuring them. We distringuish between two different methods of exploration: exploration aimed at discovering unknown phenomena and mineral deposits or completely unknown raw materials and exploration of established phenomena and deposits in order to evaluate and ensure fresh reserves of certain raw materials. In this paper we shall concern ourselves primarily with exploration of unknown phenomena or new raw materials.

D e d u c t i o n is, in my opinion, the basic principle to be applied in exploration of mineral raw materials. The point of departure should be the general geological conditions that is, the available information on the geological structure of a certain region. By studying the geological structure of a certain region, that is its lithology, age and the spatial distribution of formations comprising it, one can draw a line between the possible and the impossible, i.e. one can distinguish between the formations that may carry certain non-metallic raw materials and those which may not. (Marl for cement for instance will not be sought for in Precambrian crystalline). The most reliable information in this respect can be obtained from a g e o l o g i c a l m a p of an appropriate scale and content (containing in addition to stratographic divisions a lithological survey of formations, as complete as the scale permits and including structural elements).

Having identified the terrain which is composed of formations in which the raw material we are looking for can be expected to be found, p r o s p e c t i n g begins and a d e t a i l e d g e o l o g i c a l m a p is drawn up. The most practical scale for these maps for our purposes has been found to be 1:10,000 as it permits detailed presentation of the section of the formation which is richest in the raw material in question. A number of different specialists participate in drafting such a map while in the meantime, samples taken from the field are tested in appropriate laboratoires, to determine their mineralogical and chemical composition, their structure and texture. Bio-stratigraphic analyses are also carried out as well as all other relevant tests to determine the method of creation and origin of a certain formation. The dimensions and location of the formation, particularly its depth are explored with the help of appropriate g e o p h y s i c a l m e t h o d s (electrical resistance, conductivity etc.), t r e n c h e s and b o r e h o l e s particularly of the surface of the terrain has been sown with a crop or is covered with some other material. In the course of such exploration work, test samples are regularly taken for laboratory analyses in the aim of learning about the detailed structure of the terrain and, in the case of useful substances, about their properties: composition, set -up and quality and their modifications, if any.

> The findings of this exploratory work indicate the ore--bearing area its scope and sub-division into smaller units in terms of the probability of a definite deposit being found and provide an evaluation of the size of the deposit.

Further exploration concentrates on the identified ore--bearing area. Depending upon the type of raw material that is being explored and the form in which it occurs (large veins, small veins, layers etc.) geological maps of appropriate scales are drafted, most frequently 1:2,500 or 1:1,000. For such maps to be drafted, experts in a number of fields have to participate. Geological observation in the field and taking of samples (usually at points on a grid, the density of which depends on the scale of the map) is usually accompanied by geophysical and geochemical prospecting as well as exploratory mining work. The samples are tested in the laboratory with a view to discovering the composition and structure of the material as well as its chemical composition and other properties of relevance for application purposes; these are immediately followed by technological experiments and, in the case of raw materials intended for industrial processing or use, by semi-industrial tests of the applicability of the raw material in question. Geochemical methods are applied to learn about possible changes in the composition of the raw material in the field; some of them are, in addition, successfully applied for detection of mineral raw materials at greater depths. The ore-bearing body's position on the terrain, particularly its lay-out and dimensions are first defined by appropriate geophysical methods (depending upon the kind of raw material in question) and then by ore prospecting methods (trenches, boreholes, pits and tunnels).

Such an, essentially, multidisciplinary approach to the exploration of mineral raw materials gives us an idea of the available quantities of a certain mineral and its qualities or, simply of reliable reserves which can be applied in the economy.

The economic evaluation of these raw materials (ore exploitation and application) will be discussed elsewhere. On this particular occassion, however, we feel that another aspect of exploration should be indicated which is frequently neglected in the haste to discover industrial raw materials. I am referring to fundamental geological research.

When a really rich deposit of high quality mineral raw materials is discovered. certain fundamental geological questions such as environment and genesis of the deposit, its stratigraphic position, paleo-ecological conditions etc. remain at the level of purely academic discussions and have no bearing on the evaluation of the deposit in question. That happens only rarely however. Far more frequenntly, new reserves have to be sought out and raw materials of a superior quality. The contribution of fundamental geology to that quest is of first-class or even decisive importance. I shall mention only two cases in point from our practice.

It has been noted that the main deposits of sands, fire and ceramic clays (and others) in this country are mainly to be found in

Tertiary formations. As a result, prospecting for these raw materials has mainly concentrated on formations dating from the Tertiary molasse basins across the country. In specialized publications reports appeared on the finding of a certain deposit in such and such a "Tertiary basin" and plans for future exploration focused on basins as a whole. Many years of research into the paleo-ecological conditions and environments in which those raw materials were formed have indicated a clear connection between their formation and their distribution: high-quality quartz sands and fire clays were formed on the shelves of certain lacustrine phases and it is only in such environments that they can be found and not in the basin formations of deeper water. Once this was established, appl[illegible] research was steered accordingly and vast material means and precious time saved.

In the Eastern parts of Yugoslavia, clastic formations from the Lias have been found to contain high quality fire clays. In the same region however, we come accross similar formations by their lithological composition but different in age; they contain no fire clays. Consequently, our first step in exploration has to be to determine the age of the formation we are studying: any exploration into formations other than the Lias (which were also formed in the shallow shelf zone or the epiplatform) would be in vain. A detailed study has revealed some other important elements for applied research: even Lias formations do not contain fire clays in all stages of their development; they are to be found only in those places where Lias slates were covered by the waters of Tertiary lakes which points to the conclusion that in this new environment slates were transformed into clays by aquatolysis. It is therefore extremely important to know the genesis for any detailed exploration of Lias fire clays. Furthermore, for one to be able to determine the presence of Tertiary lakes one has to be able to identify the morphology of lake shores and shelves.

There are many such similar examples. Fundamental geological disciplines have a significant contribution to makes to exploration of raw materials. If one can establisch certain general laws for the occurence of mineral raw materials it means saving a great deal on expensive geological research work and achieving one's objective much sooner. The proper application of those laws provides the most reliable basis for the discovery of new reserves and new mineral raw materials.

POSSIBILITIES FOR THE NEW DEPOSITS DISCOVERY OF NON-METALLIC RAW MATERIALS IN YUGOSLAVIA AND IN SOME DEVELOPING COUNTRIES

The discovery of new deposits of mineral raw materials is the result, on the one hand, of the demand in industry, o other branches of the economy, for a certain raw material and, on the other, of the readiness of geologists to draw the attention of the economy to the possibilities of discovering a certain raw material. That is the way towards the development of the economy on the basis of mineral raw materials available locally, independence of imports and even the possibility of exports.

Yugoslavia commands a large and experienced body of geology experts working in geological institutions in all the republican centres, at universities or in mines and enterprises engaged in ore prospecting. In the initial stage of the development of geological services in Yugoslavia, particularly in the immediate postwar period, a certain number of Yugoslav geologists acquired the know-how they needed outside the national frontiers mostly attending post-graduate courses in developed centres in the East and in the West. Nowadays, the advanced training of personnel is ensured mainly through an exchange of experiences between individual national centres.

Thanks to such a qualified manpower and well-equipped laboratories, a large number of non-metallic raw materials have been discovered to meet the needs of the economy. In answer to the needs of the economy and considering the results of geological research so far, the range of non-metallic raw materials under exploitation is expected to be expanded shortly with vermiculites and crystalline magnesites which are essential materials for the industry of thermo-insulating and heat resistant products, that is for the construction industry in the broader sense, shipbuilding, etc.

Yugoslav experts for exploration of non-metallic mineral raw materials have been quite successful in some Third World countries and particularly in the Middle East and Africa. Let us mention phosphorite exploration in Jordan; gravel, cement and other building materials in Iraq; cement raw material in Lybia; quartz sands in Guinea Bissao; bauxite in

Guinea; graphite and ornamental stone in Mozambique... At the same time, young experts from Third World countries have been attending specialization courses at Yugoslavia's geology centres as provided for by agreements on technical cooperation between their countries and Yugoslavia. A certain number of young geologists from Mali have attended a post-graduate course in "Geozavod" and in the field, all over Yugoslavia. The same applies to a group of Iraqi geologists.

Our cooperation with the developing countries in the area of exploration and exploitation of non-metallic mineral raw materials is still inadequate. In our opinion it could take two forms:

- joint exploration for deposits of non-metallic raw materials, and
- training of researchers.

As for the possibilities for the discovery of deposits of non-metallic raw materials in the developing countries, they appear to us to be very good in view of the geologic composition of the terrain of those countries. In line with the geological classification applied in this paper, there are realistic chances of the discovery of deposits of the following raw materials by geological complexes:

In the crystalline (crystalline basement of Africa, crystalline massives in many terrains) there are various types of building stone some of which are suitable for internal and external decoration (multicoloured marbles, granites), micas and vermiculites, graphites, etc. The sedimentary cover of the crystalline varies considerably in age and composition. The older segments of it contain construction stone (sandstones and limestones) but sizeable deposits of phosphorite can also be expected in certain regions. The younger segments of the sedimentary complex occasionally contain good cement raw materials and semiprecious stones. Volcanic intrusions and eruptions provide construction stones of a broad range of applications but in view of the fact that their chemical composition is dominanantely basic(doierites) they could also be used in petrurgy. Let us also mention (once again we cannot enumerate all the raw materials) that younger formations contain sands and clays, and alluvial formations, in addition to construction gravel and sands, some engineering and precious stones.

T r a i n i n g, fundamental and advanced, of researchers can be carried out in two ways: within the framework of our scientific research centres and university departments, all levels of training are available including quick courses intended to train students for actual work in the field and in the laboratory, i.e. laboratory testing; or, alternatively, by organizing specialization courses locally in the country coucerred. Perhaps a combination of both methods would provide the best results.

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Table I

NON-METALLIC MINERAL RAW MATERIALS IN YUGOSLAVIA

EXPLORED AND MINED		REQUIRING FURTHER EXPLORATION WORK	UNDISCOVERED
1. Asbestos, chrysotile	A,2	1. Alunite	1. Asbestos, amphibole
2. Barytes	A,2	2. Al-silicates	2. Apatite
3. Bentonites	A,1,2	3. Boron raw materials	3. Calcite-optical
4. Bauxites-white	A,2	4. Bromine	4. Corundium
5. Chalk		5. Fluorite	5. Diamond
6. Clays-brick	B,1	6. Iodine	6. Fluorite-optical
7. Clays-caoline	A-B,1	7. Magnesites-crystalline	7. Phlogopite
8. Clays-ceramic and refractory		8. Natural pigments	8. Pumice
9. Clays-ceramsitic	A,1,2	9. Precious and semi-precious stones	9. Salts of tin and magnesia
10. Diatomite	A,1	10. Quartz-piezooptical	10. Strontium raw materials
11. Dolomite	A-B,2	11. Vermiculite	11. Sulphur native
12. Feldspars	A,3	12. Volcanic scoria	12. Volcanic ash
14. Garnets	A+B,1		
15. Graphite	A,3		
16. Gypsum and anhydrite	B,2		
17. Limestone	A,B,C,1,2,3		
18. Magnesite-inflitrating and sedimentary	A-B,1,2		
19. Marl-cement	A-B,1,2		
20. Muscovite	A-3		
24. Phosphorite	A-3		
28. Quartzite and other quartz raw materials	A,1,2,3		

TABLE I (cont.)

22. Perlite	A,1
27. Quartz sands	A,1
24. Sand and gravel	B,1
26. Pyrophyllite	A,3
25. Pozzuolanic additives	A,1
30 Silex	A,1
31 Table salt	A,1
13. Forsterite rocks	A-B,1,2,3
23. Petrurgy rocks	A-B,1,2,3
29. Roof slate	A-B,3
32. Talc	A,1,2
11a.Technical construction stone	B,1,2,3
21. Ornamental construction stone	B,1,2,3
34. Wollastonite	A,1
35. Zeolites	A,1

NOTE: This Table has been compiled according to B.Vakanjac (1979) with changes and amendments made to adjust it to the present situation and the classification used in this paper. A,B,C denotes the division into groups according to application; 1,2 and 3 are groups according to the geological environment in which the listed non- [illegible] raw materials have been discovered.