GEOLOGY AND MINING RELATIONSHIP

Prof.dr.H.C. GHEORGHE C. POPESCU
Universitatea Bucureşti

ABSTRACT: *The relation between geology and mining is perfect symbiosis between a natural science and an engineering. Geological knowledge has been exercised from the very dawn of mankind, when first information on stones and minerals was gained. The Neolithic man has exploited silex, volcanic glass – the obsidian – that could be easily chipped, yielding nice and sharp, yet fragile tools. It is obvious that various hard and nicely colored minerals such as agate, charneol, turquoise, hematite, etc. could not pass unobserved, and the primitive man extensively used them as adornments. Later on, during the last two thousand years BC, primitive miners have explored and extracted metallic ores, firstly copper, then bronze and iron.*

Keywords: *geology, mining , stones, minerals, ores, explored, extracted.*

Introduction

The relation suggested by the title is an inciting subject that allows an incursion in the history of science and civilization and that gives an example of a perfect symbiosis between a natural science and an engineering key field.

Geology has separated relatively late as a self-standing science, that is, in the XVIII-th century, together with biology. However, primary elements of geology, and no less of mining, have appeared much earlier. Geological knowledge has been exercised from the very dawn of mankind, when first information on stones and minerals was gained.

Today, geology appears as a complex science, a system organized on two levels: a central one, playing the role of a core, which includes the disciplines studying minerals, and another – external – one, grouping those branches of science that interact with the fundamental areas of knowledge (Fig.1).

As anyone knows, the first tools used by man were made of stone: axes, silex and obsidian blades, arrow and spear heads, all used mostly for hunting (Fig.2).

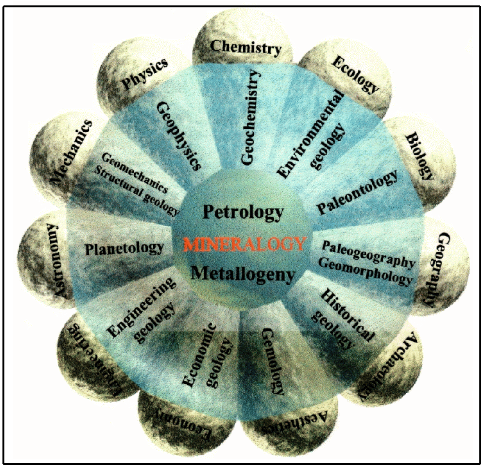

Fig. 1. The branches of Geology in relation with the major fields of human knowledge

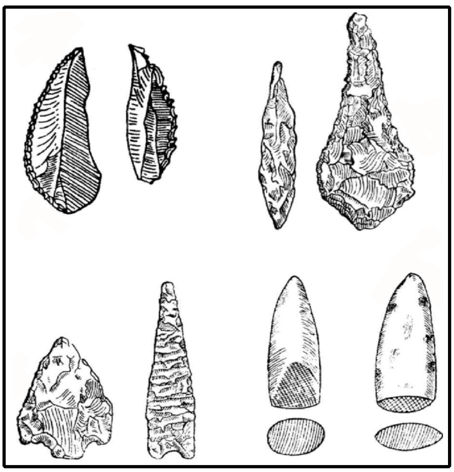

Fig. 2. Paleolithic and Neolithic stone tools

Minerals may have been noticed even before stones, mostly due to their aesthetic appearance.

Many of them may have been used as adornments or magic objects. First to be used were the precious stones and then, the metals.

As mentioned earlier, many tools and weapons used by primitive man were made of silex. This suggests that a choice has been made, based on knowing the properties of a particular stone, out of the many occurring on the Earth's surface.

Of course, tools were made also of other stones: quartz, granite, schists, quartzite, hard limestone, but the preferred material was silex, especially due to its property of breaking into sharp chips and to stand prolonged employment. The silex has been used for hundreds of thousands of years, from the epoch of unprocessed stones – whose vestiges were found at Saint-Priest and Abeville – till 2500 years BC, when metals became common.

Soon after depleting local surface sources of silex, pre-historic men began to look for other, not so obvious occurrences, that is, they began to "explore". They most probably noticed a certain position and a certain association of silex, with respect to other rocks in the Earth's crust, or to certain strata, doing basically what we call today as Geology. It then followed the extraction of silex, by digging galleries and shafts, that is by "mining". Such activity was common for the last 5,000 years BC, namely, during Neolithic.

Beside silex, the Neolithic man, has also exploited volcanic glass – the obsidian – that could be easily chipped, yielding nice and sharp, yet fragile tools. It is obvious that various hard and nicely colored minerals such as agate, charneol, turquoise, hematite, etc. could not pass unobserved, and the primitive man extensively used them as adornments.

Beside silex, the Neolithic man, has also exploited volcanic glass – the obsidian – that could be easily chipped, yielding nice and sharp, yet fragile tools. It is obvious that various hard and nicely colored minerals such as agate, charneol, turquoise, hematite, etc. could not pass unobserved, and the primitive man extensively used them as adornments.

Later on, during the last two thousand years BC, primitive miners have explored and extracted metallic ores, firstly copper, then bronze and iron.

Metals and human society

The first native metal ever noticed by man – especially for its colour – was gold (Fig.3). Due to its malleability, gold distinguishes clearly from the hard and brittle stones used for tools. Gold could be plied into thin sheets or strings, mold in various shapes. The technique of processing gold has well preceded its extraction from ores. Gold was always a precious metal, valuable beyond its actual practical usage. It has been assigned with mystical powers, and imposed itself as a symbol of wealth and power Fig.4). Opposite to bronze or iron, gold has not given its name to any epoch in the history of mankind. Instead, it has been a permanent reference point in the history of civilization.

Copper (Fig.5) – which may be as glittering as gold, when unoxidized – could be used for making tools. This determined its extraction from carbonate and sulfidic ores, that were easy to find and to process (Fig. 6).

Subsequently, copper and tin ores (Fig.7) have been used – probably accidentally in the beginning – to obtain bronze (an alloy of copper and tin). It is hard to believe however, that the prehistoric man discovered the recipise of this alloy by means of metallurgical studies. The discovery of bronze seems to have been rather an accident, linked to the way these ancient people used to protect their bonfires. Among the blocks of rock fencing the fire, there might have been fragments of tin and copper ores whose melting produced a metal which was different from copper – already well known to man – but with superior properties compared to copper.

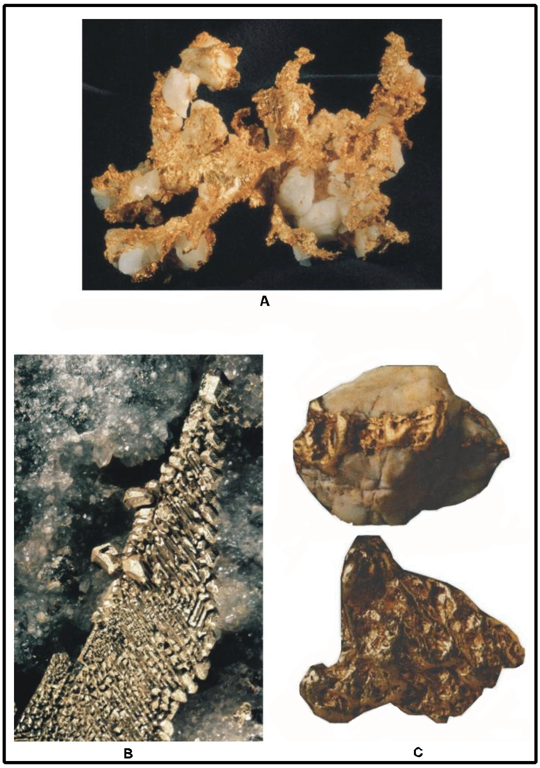

Fig. 3. Native gold. A. foils (Ontario); B. skeletal (Sacaramb); C. nuggets (California)

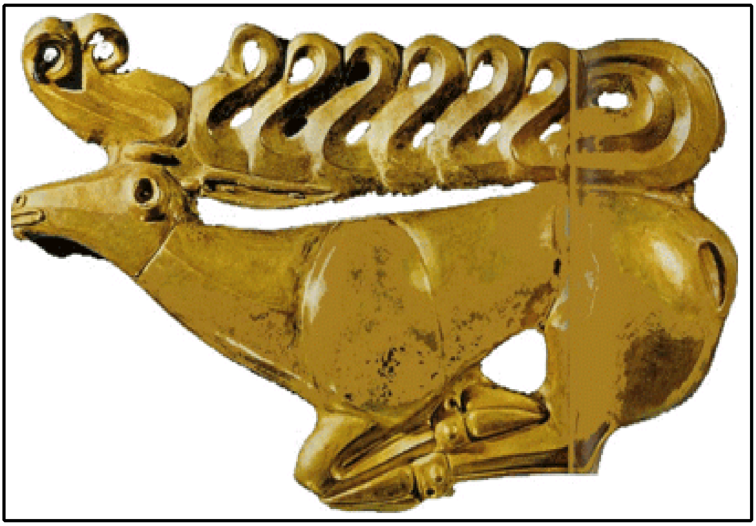

Fig. 4. A gold emblem of antiquity; the hairpin of a tribe leader from the Central Asian steppes, the VII-th century BC.

Fig. 5. Native copper (Rio Tinto, Spain)

Fig. 6. Secondary copper minerals (Rio Tinto, Spain)1-stalactite of copper sulfates; 2-kornelite; 3-oquimbite; 4-rhomboclase;5-halotrichite; 6-coquimbite-chalcantite; 7-kornelite; 8-fibrous aggregate of epsomite.

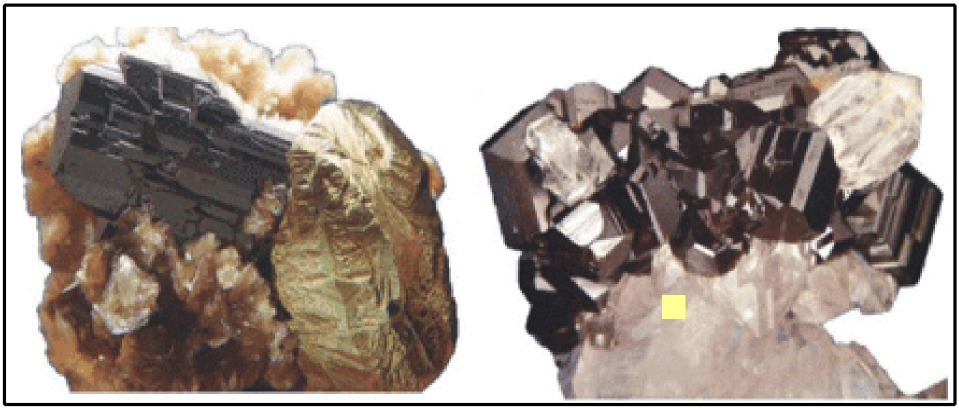

Fig. 7. Copper and tin ores (Panasqueira-Portugal)
A. chalcopyrite and ferberite; B. cassiterite and quartz

The manufacturing of metal tools has represented an obvious technical progress. Metal tools were much more durable than those made of stone. Metal weapons were also much more efficient, both in hunting and war. But on the other hand, for many centuries, metals have been expensive. The word “metal” itself derives from a Greek root meaning “to search”, suggesting that it was a matter of a very rare material. This is why metals have been used especially for manufacturing luxury accessories, where as agriculture and a large part of the craftsmanship have used stone tools.

Only bronze – with a low melting point – could be founded into casts and hot worked. With its resistance to oxidation, bronze was superior to stone and began to be used in manufacturing a large range of objects, tools and weapons.

The Bronze Age thus took the place of the Stone Age.

Iron has been initially as rare as copper, maybe even rarer. Its main source was represented by meteorites rather than native, earthly iron (Fig.8).

Fig. 8. Iron meteorite (Portland, U.S.A.)

The iron used in antiquity (the XV-th century BC) was obtained by reducing iron oxides in burning charcoal, inside clay furnaces and with manually driven bellows.

The resulting spongy iron lump was then hammered. Through subsequent forging and welding, one could eventually obtain more complicated forms. The technique was totally different from that involved in copper processing, and it has been kept secret for a long time. The keepers of these secret were the Chalybe tribe from Caucasus, the Chinese and the Indians, who manufactured the renowned Damascus swords or the legendary charmed swords (e.g. King Arthur's "Excalibur", Siegfried's "Balmung").

However, for a long period of time, iron could not entirely replace bronze, but rather complemented it. During the Iron Age, even more bronze than in the Bronze Age has been produced. This was due to an increased demand of tools and weapons. Hardened steel was much rarer than bronze, and excepting its use in making weapons, it did not play an important role in technics until the advent of industrial revolution, in the XVIII-th century.

Such an assertion should however be amended if we only take into consideration the Roman mining carried out in the Apuseni Mountains. To dig the famous galleries at Rosia Montana and in other places throughout Apuseni, the Romans used, beside fire, the iron hammer and chisel. This technique was very efficient and contributed to the considerable quantities of gold produced during the Roman occupation of Dacia.

This historical picture pleads for the idea that mining and geology have been little differentiated during Antiquity, Middle Ages, and until the XVIII-th century.

The ultimate expression of the unity between mining, geology and metallurgy is the work „De Re Metallica", written by Georg Bauer alias Georgius Agricola (1490–1555). This work has been considered by the science historians as "the most complete technical treatise ever written, because it describes not only minerals and metals, but also the practice and the economy of mining exploitations in that time" (J. D. Bernal, 1964). (Fig.9).

Fig. 9. Front cover of the Latin edition of „De Re Metallica" published in 1556.

The most important technical progress during Renaissance has taken place in the close connected fields of mining, metallurgy and chemistry. The increased need of metals has brought along a larger number of mines being opened, firstly in Germany and then in America. During the Middle Ages, mining has been represented by small private initiatives or associative groups of free miners, who carried exploration and extraction on their own. They paid taxes directly to the king or prince who, in turn, protected them against local feudal authorities. Along with the development of mining, free miners began to associate, sharing the benefices allotment wise.

Even Agricola, the author of the above-mentioned "De Re Metallica", who was the official physician of the Saxonian mines, held shares at the most profitable mines.

As mines were becoming deeper and deeper, pumping and craning devices were in ever greater demand. This led to an increased interest in the principles of mechanics and hydrotechnics (Fig. 10).

Following the decline of mining in Germany – mostly due to religious wars – the German miners and metallurgists emigrated to Spain, England and the New World – one of the causes behind the future wealth of these territories.

The melting of metals has been a true school for chemistry. The increasingly developing mining activity was to bring to surface new ores and even new metals – zinc, bismuth (gold-like colored metal), cobalt (from Kobold = the mine's gnome) – or the fake brass.

The ways of manipulating and processing the new metal ores has led to the establishment of a new general theory of chemistry, mainly pointing to oxidation and reduction processes, distillation and amalgamation. The quantitative chemical analysis necessary for the determi-nation of metal contents, was nothing else but a small scale reproduction of a melting process using a defined quantity of ore. This was the foundation of chemical expertise and analysis.

Much more significant transformations were taking place in the field of less "appealing" products such as those made of iron. As far back as the XIV-th century, the metallurgy of iron knew some fundamental changes, mainly linked with the processing of cast iron. Even though cast iron had been known long before, in China (II-nd century BC), its advent in Europe had nothing to do with that. The appearance of cast iron in Europe has been the consequence of the ever increasing production of iron. For three thousand years, iron had been produced in small furnaces, by reduction of ores with charcoal, at small temperatures (Fig.11).

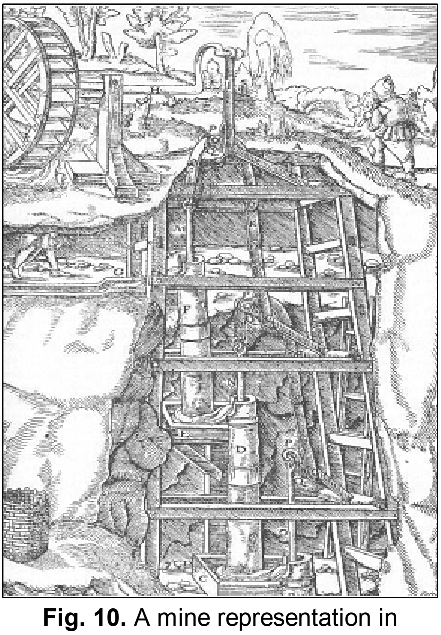

Fig. 10. A mine representation in Agricola's "De Re Metalica"

Fig. 11. Furnace for melting iron ores

Along with the arrival of larger furnaces, air needed to be introduced with the aid of hydraulic bellows, thus producing very high temperatures. Melted iron poured along a dent placed in the front of the furnace. The iron cast obtained in this way was difficult to purify, but step by step, the process has been improved, and the blast furnaces gradually replaced the old ones.

Towards the end of the XVIII-th century, iron production passed from hundreds of kilograms to tons, temporarily inducing a shortage in charcoal supplies. Traditional iron manufacturers – England, France, Germany – had to leave their leading position to the advantage of Russia and Sweden which had immense forests. After other two centuries, coal began to be extensively used. The wide coal resources of England and Germany have brought these nations again to supremacy, as leading producers of iron cast and then, of steel.

Out of the three main methods of producing steel– Bessemer, Siemens and Thomas, the first two complied with the growing demand of steel, whereas the third proved to be crucial in recovering the immense iron ore resources from the Lake Superior area (fig.12), Lorene, Russia, India, and more recently, from Australia.

In the second half of the XX-th century, the demands pointed rather to a wide variety of metals. Yet, the three metals that had influenced the last 2000 years in the history of mankind: gold, copper and iron, still held a central economic role.

The philosophy of ore exploration

Until the XIX-th century, autodidactic and encyclopedic prospectors could meet the demands of new ores only for semi-industrial production of metals. However, during the industrial revolution, the empirical approach of ore exploration was no longer adequate. In the beginning, the quest for metals and ores has been under the influence of the idea that **"Ore deposits are to be found where they occur"**. The empirical research that followed up, used a step by step strategy, a "centrifugal" principle stating that **"Ore deposits are to be found near other ore deposits"**. One has to admit that up to this stage, geology had very little influence. After that however, the analysis of geological similitude was to be the basis for the discovery of new ore deposits. This principle of analogy had no chance other than being founded on scientific knowledge.

Geology has become a science relatively late. In the beginning, it was basically a field science. The mineral, rock and fossil collector could not achieve much – the most he could do was to wonder in front of a multitude of odd things produced by Earth.

The miner, on the other hand, was so preoccupied by the ore, by all the indications that signaled its existence and by its association with the host rocks, that he could not explain – and neither had the curiosity do so – the ore genesis and history, and even less, the Earth's structure and history. However, along with a growing interest for nature, an ever increasing number of XVIII-th century scientists started to study rocks and fossils.

They were thus able to state that shells found in the mountains proved that those areas had been ocean floors – confirming an idea first stated by what Leonardo da Vinci. From this point on, up to speculating upon an origin of life lost in immemorial times, was only a short distance. The travels and the amazing stories about volcanoes and earth-quakes from various parts of the world have stimulated a new conception about Earth, stating that its crust underwent continuous cataclysms during which it cracked and/or folded, due to an internal fire. This started a sterile polemic between the "neptunists" – whose exponent was the famous professor Werner from the Freiberg Mining Academy – and the "plutonists" – illustriously represented by the scotsman Hutton (Fig. 13). In his famous work „**The theory of the Earth"** – Hutton exposed a revolu-tionary theory – the uniformism – which stated that the processes we see operating to form and shape the Earth today have always operated in the past. For this, Hutton is considered the father of geology. As his succesor – the English Lyell (Fig. 12) – later demonstrated: **"the Present is the key to explain the Past"**. Lyell ammended the uniformism and renamed it as the principle of actualism.

Beside the principle of superposition of rock strata formulated two hundred years earlier by Nicolaus Steno, this principle constitutes the foundation of geology.

Without these principles, geology would not have any sense and could not be conceived. How these principles helped to discover ore deposits will be a matter discussed in the following paragraphs.

A. von Humboldt (Fig. 13), was the first to observe the links between metallic concentrations and igneous rocks. This idea has been perfected and scientifically substantiated by Ellie de Beaumont, in his theory regarding volcanic and metallic emanations. In fact, this theory is an expression of two fundamental principles governing the contemporary metallogeny – the principle of actualism (as long as today we observe deposition of metals – especially sulfides – in volcanic fields, the old ore deposits should have formed in the same way), and the principle of similarity (the rocks and ores have formed by the same geological processes).

Fig. 12. Modern machinery for extracting iron from poor ores, by melting them under electric arc (2500ºC)

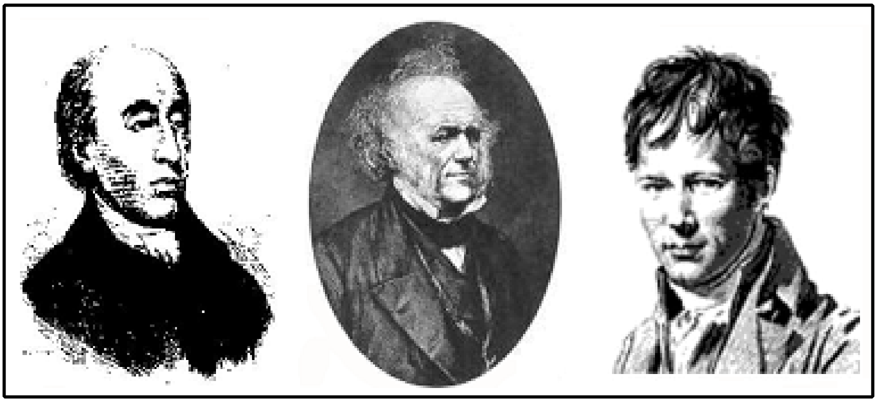

Fig. 13. The founders of Geology: J. Hutton, Ch. Lyell, A.von Humboldt

These principles agreed with the seen reality of today's ore deposits distributed mainly in volcanic areas. The concentrated expression of the above is in the saying: **"if you want to discover ore deposits then go in the mountains**". This kind of thought had a practical and guiding meaning and reflected in the "centrifugal" principle of prospecting new ore deposits in the vicinity of known ones.

The cradle of mining in Metaliferi Mountains – which is older than two thousand years, illustrates the above considerations. Gold in these mountains has been extracted first by the Agathyrsi tribes, and then by the Dacians and Romans. Gold represented in fact, the true reason behind the Roman-Dacians wars. By the time of the Roman conquest, the Dacian thesaurus was estimated at 150,000 kg gold, and represented an extraordinary war capture; to honor its victory against the Dacians, Rome organized celebrations for 100 days. During the Roman occupation of Dacia approximately 500,000 kgs. of gold have been extracted (Fig. 14). It is obvious that the mining technology introduced by the Romans – with the hammer and chisel playing a fundamental role – has contributed decisively to increasing the gold production in Apuseni Mts. That is, in the same perimeter where free gold veins such as those of Roşia Montană (Alburnus maior), Bucium, Zlatna (Ampelum), Almaş, Stănija, Ruda Caraci, had been known long before.

As to the application of the principle of analogy in discovering ore deposits, the case of the Siberian diamonds is well known. In the early '50s of the XX-th century, Prof. Semenenco has drawn the attention upon the geological similarities between Siberia and South Africa (Fig.15). On this basis he suggested an extensive diamond search campaign in the Yakutian area. As the country needed diamonds and had plenty of geologists (over 10,000), a fever of Siberian diamonds broke out.

After few years, first diamonds where discovered in the frozen alluvia of Yakutia, and next, their primary source areas – the kimberlitic chimneys. Even the art of cinematography has immortalized this event in the excellent movie by Kalatozov, the same who gained the 1959 "Palme d'Or", at Cannes, with "The cranes are flying".

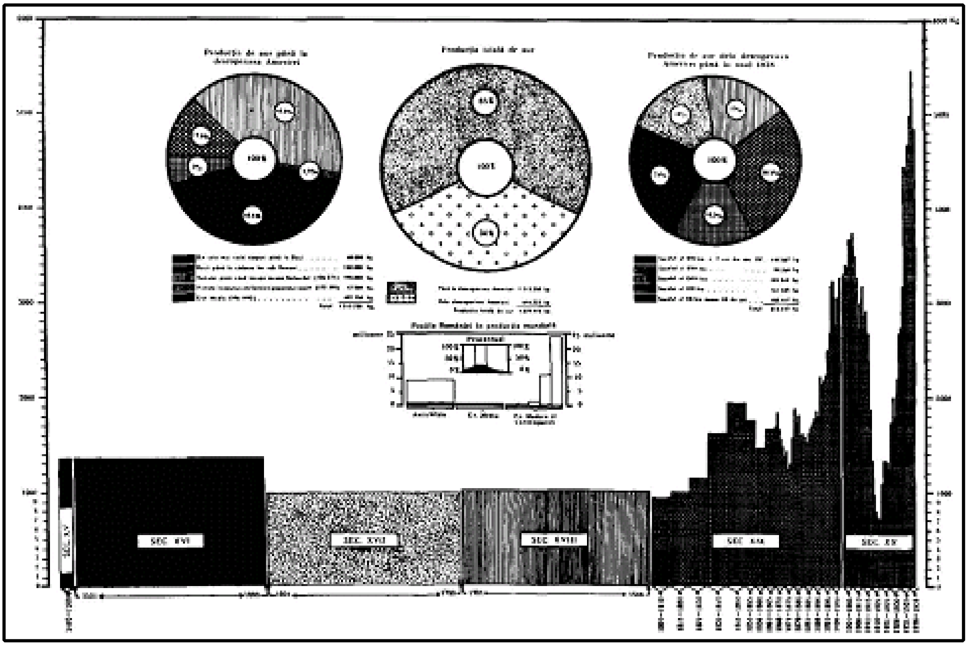

Fig. 14. Gold production of Romania until 1939 (I. Haiduc, 1940)

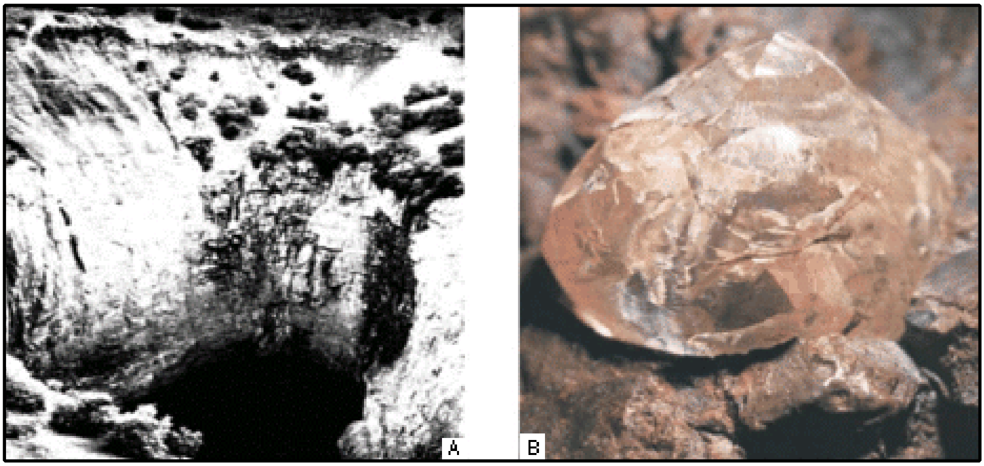

Fig. 15. The Big Hole" at Kimberley, left by the trail of diamonds down a kimberlitic chimney (A), primary diamond of 5mm, from Kimberley (B)

One should not overlook the fact that due to the progress achieved in the research of extraterrestrial space, geology has overcome its initial object from which it actually received its name: Geia = Earth, and added a new branch: the Planetology. Thus, geology could benefit from a new space technology – the remote sensing.

By investigating the interaction between electromagnetic waves and terrestrial environments, some extraordinary images of the geological structures, including those rich in mineral resources (Fig.16) could be obtained.

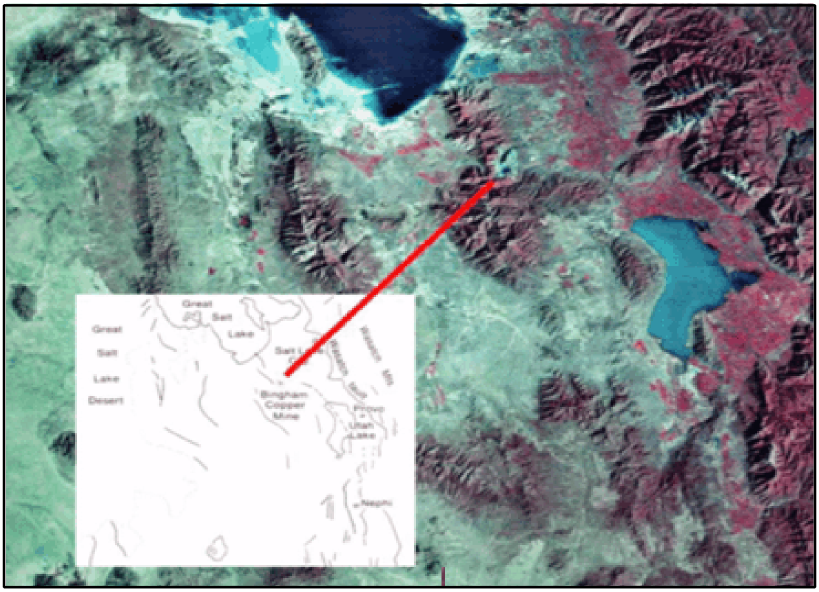

Fig. 16. Satellite image of a part of Rocky Mountains, in the region of the Binghamcopper ore deposit

Thus, one could obtain cartographic-geologic images of territories still unseen by man – in deserts or under the ice covers. Through analogy with lands well known for their mineral resources, it has been possible to predict their existence even in such remote, still unknown areas. This has brought back an old concept that had been abandoned for a long time – the liniamentarism. The reactualization of this concept has been made possible only by the remote sensing, and has helped in the discovery of several gold deposits in old terrains such as those from South Africa, Namibia, South Australia, and in our case, in the South Carpathians.

At the end of the millenium, geology brought a revolutionary and profound concept, with implications that exceeded by far its object: the Global Tectonics. It was called "global" not because it referred to the Earth's Globe, but for its general and compre-hensive approach to all fundamental problems of geology especially to those having a high impact on human knowledge: the formation of mountain chains, of oceans and seas, the transformation of continents – their movements and evolution. Perhaps only the XIX-th century's concept of evolutionism had such a dramatic influence on natural sciences.

The concept of global tectonics emerged gradually from the initial core of the continental drift – developed in the last fifties and the sixties, together with the newly achieved knowledge on the morphology and content of the ocean floor. It eventually evolved into two theories: the ocean floor spreading and the plate tectonics.

The global tectonics has been dominating the human knowledge about Earth and nature, for more than 30 years. Obviously, the concepts and the practice of ore-deposits discovery could not escape its influence. The global tectonics placed the formation of ore-deposits and of related rocks in the areas of strongest interaction between the lithospheric plates, thus yielding an unprecedented strategy for the exploration of ore deposits. Never a scientific theory has been applied so rapidly and so successfully as the plate tectonics.

Starting from a deterministic relationship between subduction areas and calc-alkaline (andesitic) magmas associated with large accumulation of copper, molybdenum and gold – the porphyry copper type (Fig. 17), a veritable copper and gold rush broke out in the actual and prequaternary subduction areas (Fig.18).

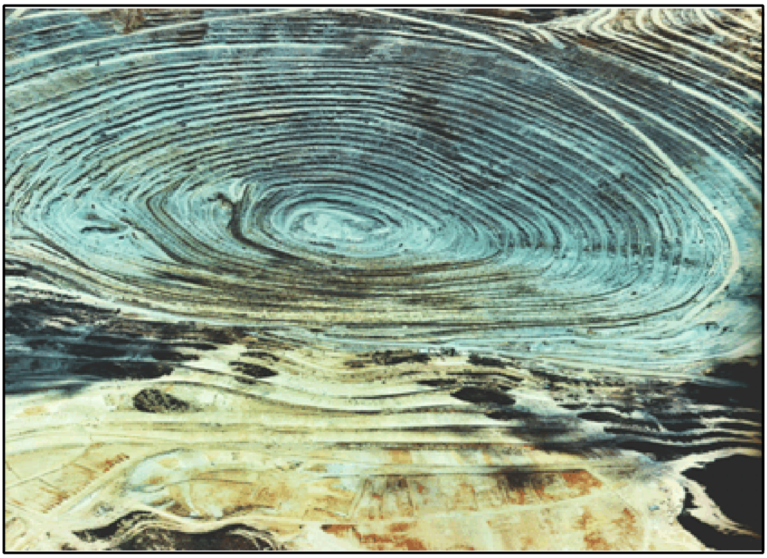

Fig. 17. Bingham porphyry-copper ore deposit (Utah)

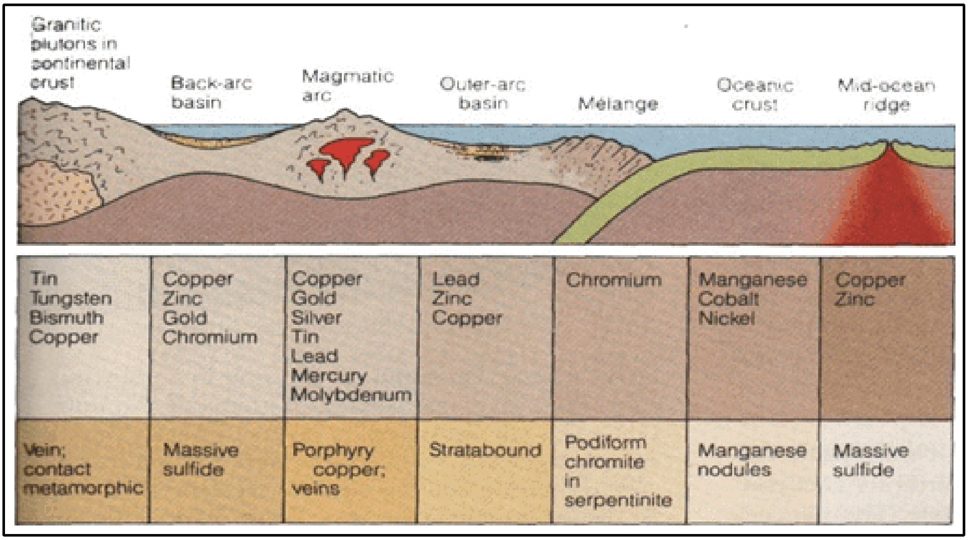

Fig. 18. The correlation between the lithospheric plate margins and the metals that concentrate in this areas

The results have arisen very quickly. New ore deposits have been found in areas that had been previously well known for their mineralized structures, and also in areas where nobody had had a clue about any ore deposits: it was the case of some accumulations in Peru, Bolivia, Iran, Indonesia, the Philippines, Polynesia and not the least, in our country. It is equally true that geophysics contributed a lot to this success. The magnetometry proved to be a very efficient method to spot porphyry structures, especially due to the high magnetite contents of these deposits.

In the end, we will give two examples to illustrate the above considerations. The first example comes from the Indonesian Iryan, Papua-New Guinea island. The Ertsberg (The Ore Mountain) ore deposit, discovered by an Dutch expedition, in dense forest, at over 4300 meters in altitude, as early as 1936, has remained incaccessible for a long time.

During the ‘60s, the American mining company Freeport – McMaran, decided to invest about 1 billion USD in this project. The helicopters began to fly over the jungle, modern roads began to advance slowly (4-6 m/day) in rough terrains with inclines exceeding 70 ‰.

Huge efforts were made, but eventually everything was worthy, as an immense profit expected the explorers: a “capture” of 40 billions $.

In 1988, the Freeport geologists discovered another ore-deposit: Grasberg (Fig. 20), lying at an even higher altitude – 4600 m. Its exploitation meant an even more extensive use of helicopters and giant bulldozers, working in an extremely rugged terrain, with cascades of over 600 m. The ore deposit was estimated at 60 billion USD, and represented the biggest and richest gold deposit in the world. Its daily ore production is of 160,000 tons, and it is expected to grow in the near future, to 300,000 tons.

These, and other similar ore deposits could not possibly be exploited unless modern extracting and ore-processing technologies were involved.

It is an example of convergence of science and technology, where a revolutionary idea – the plate tectonics – is well served by a break-trough heavy engineering. Such convergence is also well illustrated in the case of our country. The gold fields in Brad-Săcărâmb and Roşia-Bucium districts, have been extensively explored and mined in the ‘50s and ‘60s.

The geology of these areas, was re-examined in the new context of the plate tectonics. Thus, several structures with disseminated copper – much poorer in comparison with their vein counterparts – could pass the productivity exam, of course, by using technology adapted to intensive large scale exploitation, by excavating and by moving mining masses of previously unimaginable volumes, and in favorable economic circumstances.Starting from a deterministic relationship between subduction areas and calc-alkaline (andesitic) magmas associated with large accumulation of copper, molybdenum and gold – the porphyry copper type (Fig. 17), a veritable copper and gold rush broke out in the actual and pre-quaternary subduction areas (Fig.18).

The results have arisen very quickly. New ore deposits have been found in areas that had been previously well known for their mineralized structures, and also in areas where nobody had had a clue about any ore deposits: it was the case of some accumulations in Peru, Bolivia, Iran, Indonesia, the Philippines, Polynesia and not the least, in our country. It is equally true that geophysics contributed a lot to this success. The magnetometry proved to be a very efficient method to spot porphyry structures, especially due to the high magnetite contents of these deposits.

In the end, we will give two examples to illustrate the above considerations. The first example comes from the Indonesian Iryan, Papua-New Guinea island. The Ertsberg (The Ore Mountain) ore deposit, discovered by an Dutch expedition, in dense forest, at over 4300 meters in altitude, as early as 1936, has remained incaccessible for a long time. During the '60s, the American mining company Freeport – McMaran, decided to invest about 1 billion USD in this project. The helicopters began to fly over the jungle, modern roads began to advance slowly (4-6 m/day) in rough terrains with inclines exceeding 70 ‰. Huge efforts were made, but eventually everything was worthy, as an immense profit expected the explorers: a "capture" of 40 billions $.

In 1988, the Freeport geologists discovered another ore-deposit: Grasberg (Fig. 19), lying at an even higher altitude – 4600 m. Its exploitation meant an even more extensive use of helicopters and giant bulldozers, working in an extremely rugged terrain, with cascades of over 600 m. The ore deposit was estimated at 60 billion USD, and represented the biggest and richest gold deposit in the world. Its daily ore production is of 160,000 tons, and it is expected to grow in the near future, to 300,000 tons.

These, and other similar ore deposits could not possibly be exploited unless modern extracting and ore-processing technologies were involved. It is an example of convergence of science and technology, where a revolutionary idea – the plate tectonics – is well served by a break-trough heavy engineering. Such convergence is also well illustrated in the case of our country. The gold fields in Brad-Săcărâmb and Roşia-Bucium districts, have been extensively explored and mined in the '50s and '60s.

The geology of these areas, was re-examined in the new context of the plate tectonics. Thus, several structures with disseminated copper – much poorer in comparison with their vein counterparts – could pass the productivity exam, of course, by using technology adapted to intensive large scale exploitation, by excavating and by moving mining masses of previously unimaginable volumes, and in favorable economic circumstancesIn just few years, so many copper and gold deposits have been discovered, that they exceeded in volume all that had been discovered in the previous decades (Fig.20). We can conclude that the relation between geology and mining is one of unity – tight and mutually determined. The progress of geology gives mining unlimited fronts of action, and the progress of them both, serves the human civilization, by yielding what we now so commonly call "mineral raw materials" – without which the progress of humankind was not, it is not and will never be possible.

Fig. 19. Aerial photo of the Grasberg mine (West Iryan, Papua-New Guinea)

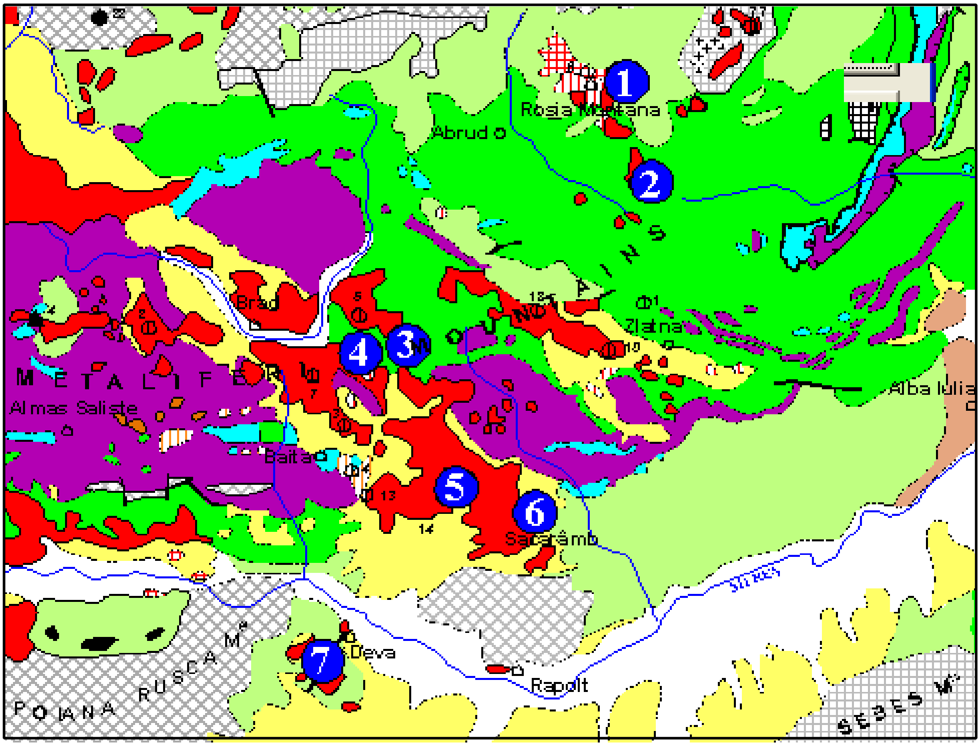

Fig. 20. The porphyry-copper ore deposits found in the '70s, in the Metaliferi Mts. 1-Roşia Poieni, 2-Bucium-Tarniţa, 3-Bucureşci-Rovona, 4-Musariu Nopu, 5-Bolcana, 6-Săcărâmb, 7-Deva

REFERENCES

1. Bleiser A. (1966) – *Life le monde vivant*, La Terre. Colection Life, Paris.
2. Bernal D.J. (1964) – *Ştiința în istoria societății*, Ed. Politică, Bucureşti.
3. Brana V. (1958) – *Zăcămintele metalifere ale subsolului românesc*, Ed Ştiințifică, Bucureşti.
4. Ďuďa R., Luboš R. (1990) – *Minerals of the World* ,Arch Cape Press, New York.
5. Haiduc I. (1940) – *Industria aurului din România*, Imprimeriile „Adevărul” SA, Bucureşti.
6. Hamblin K.W. (1975) – *The Earth's Dinamics Systems*, Sc. Ed. Burgess Publ.Co, Mineapolis, Minnesota.
7. Popescu Gh.C. (1986) – *Metalogenie aplicată şi prognoză geologică*, Partea II-a. Ed. Universității din Bucureşti.
8. Taton R. (ed.) (1970) – *Ştiința antică şi medievală*, Ed. Ştiințifică, Bucureşti.
9. Taton R. (ed.) (1972) – *Ştiința contemporană*, Partea I-a. Ed. Ştiințifică, Bucureşti.
10. Taton R. (ed.) (1976) – *Ştiința contemporană*, Partea II-a. Ed. Ştiintifică, Bucureşti.
11. Skinner G., Porter St. (1989) – The Dynamic Earth. J.Wiley & Sons. Inc., printed in USA.
12. *** Bocamina, Revista de Minerales y Yacimientos de Espana, 1997, Especial International Portugal .
13. *** Bocamina, Revista de Minerales y Yacimientos de Espana.