History of chemical mineralogy in Russia (1740-1790)

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Abstract. Until the end of the XVIII century, mineralogy as an independent science did not exist. Mineralogy, in essence, was called the science of ore deposits in its modern sense. Then, there was no clear definition of the term “mineral.” This concept included not only minerals in the proper sense of the word, but also ores, rocks, and fossils. Due to the low general level of knowledge by the middle of the XVIII century, there was no information on the chemical composition of minerals. Of all the chemical elements in the time of Lomonosov (until 1765), only 17 were known: carbon, phosphorus, sulfur, iron, nickel, cobalt, copper, zinc, arsenic, silver, tin, antimony, platinum, gold, mercury, lead and bismuth. Later, until 1790, 11 more chemical elements were discovered: nitrogen, oxygen, chlorine, manganese, barium, molybdenum, tungsten, tellurium, hydrogen, zirconium, uranium. Lomonosov laid the chemical study of minerals using qualitative and primitive quantitative analyzes. Along with chemical analyzes, physical experiments were carried out to study minerals. The scientist had the idea of synthesizing minerals, artificially obtaining salts, a number of ore and other minerals. Thanks to the efforts of Lomonosov, the first scientific chemical laboratory was built and opened in St. Petersburg. Scientists covered various issues of mineral formation, including deposition methods and sources of mineral matter, and paragenetic associations of minerals.

1. Introduction
To illuminate the historical situation of the origin of chemical mineralogy in Russia, it is necessary, at least in the most general terms, to briefly characterize the conditions in which natural sciences developed in the 18th century.

Since the beginning of the 18th century, Russia has witnessed an economic boom in industry and trade caused by the transformations of Peter I. The development of industry required intensive research into natural wealth. In the first half of the XVIII century, there was an expansion and improvement of iron and copper smelters in the old regions of the country: Tula, Prioksko-Ryazan, etc., the emergence of new plants in the Lipetsk, Bryansk regions and the Olonets region; an increase in the number of copper and silver-lead mines in Altai, in the Nerchinsk and Olonets regions; opening of the Donetsk and Kuznetsk coal basins; native sulfur deposits in Ukraine.

The leading position in the mining industry was occupied by the Urals, where rich deposits of magnetite, limonite, copper ores, "stone tow" (asbestos) and colored stones were discovered. In 1745, mining of primary gold began at the Berezovsky mine. The country fully satisfied its needs for iron and began to export metal: in 1731, Russia exported 9.5 thousand tons of pig iron and up to 16 thousand tons in 1751-1760 and has become, along with Sweden, the main supplier of iron in the world market. In the same period, the number of textile enterprises increased, and glass production and
glassmaking developed and expanded, which contributed to an increase in the production of nitrate, potash, alum, paints and other types of mineral raw materials.

The development of industry and the opening of mines was carried out through the organization of mining on a state scale. In 1700, Peter I created the first mining institution “Order of Ore Mining” [1] then renamed to the Berg College (1718) and later to the Scientific Committee of the Department of Mining and Salt Affairs (1807).

The study of the country’s mineral wealth was carried out by expeditions, the initiator of which in the first half of the 18th century was Peter I. They were headed by the Academy of Sciences. Several detachments were sent to various parts of the country: Central Russia (Kapustin, 1721; Nikulin and Rondaler, 1724; Sannikov, 1755, etc.); areas of Khiva and Bukhara (Buchholz and Bekovich, 1713-1722); Siberia (Messerschmidt, 1720-1727); Kamchatka (Bering and Chirikov, 1725-1755; Gmelin, 1733-1743; Krasheninnikov, 1737-1743; Steller, 1740-1744) [2].

2. Results

In the second half of the XVIII century, the initiator of the preparation of “astronomical-geographical” academic expeditions was M.V. Lomonosov. These famous academic expeditions were carried out after the death of Lomonosov in 1768-1774. The first Orenburg expedition was led by P.S. Pallas; the second one in the east and north of European Russia was led by I.I. Lepekhin; the third one (Astrakhan expedition) was led by S.G. Gmelin; the fourth one (Caucasian expedition) was led by I.A. Guiderstedt; the fifth one, which studied the vast territories of the Southern Urals, Altai, Western Siberia, Kyrgyzstan and the Astrakhan Territory was led by N.N. Falk [3]. The expeditions were complex and covered issues of geography, geology, mineralogy, zoology, botany, ethnography. They were of great practical and scientific importance and expanded knowledge in the field of regional and applied mineralogy.

The scientific centers of Russia at that time were the following. 1) St. Petersburg Academy of Sciences (1725). In the first popular science journal “Notes on Vedomosti” published by the Academy, then in the scientific journals “Comments” and “New Comments”, articles were published on geological topics by V.N. Tatishcheva, G.V. Richman, L. Euler, M.V. Lomonosov and others. 2) Moscow University (1755). A year later, a printing house was opened at the university, where in 1757 the first volume of Collected Works was printed by M.V. Lomonosov. 3) Free Economic Society (1765), which published its “Proceedings” in various fields of knowledge, including geology. 4) St. Petersburg Mining School (1773), which trained many specialists in geology and mining.

There was no chemical science until the end of the XVIII century, as well as mineralogical one. It was still dominated by a number of alchemical ideas about the origin of minerals and ores, about the possible transformation of some metals into others, etc. New ideas in chemistry were based on the analysis of accumulated experimental data. The main task of chemistry was to study the composition and properties of minerals and other bodies, to find out what substances they consist of and what their properties are. Among chemical compounds, acids, bases, and salts have been experimentally established.

In the 70s of the XVIII century, discoveries were made that shook old ideas about combustion processes and chemical reactions. In 1774, the English chemist J. Priestley obtained “fiery air” (oxygen). By a series of accurate experiments, the French chemist A. Lavoisier proved that when burning tin, mercury and other metals, the weight increases, i.e. there is no decomposition of these metals with the release of phlogiston, but their combination with oxygen occurs. He used quantitative methods of chemical research using weights. Based on oxygen theory in 1787-1789 Lavoisier created a new chemical classification of oxides, acids and salts according to the degrees of oxidation of the elements that form the bases of salts, compiled the first list of chemical elements and experimentally substantiated the law of conservation of mass of matter.

For Russia of the first half of the XVIII century, practical application of chemistry is characteristic. Chemical knowledge was necessary in the dyeing and skinning, salt and pitch making, in the manufacture of gunpowder, in metallurgy and assay works. Assay laboratories were located at the
Central Laboratory of the Berg College, the Mint, at the metallurgical plants of the Urals and in other places where analyzes were performed on precious metals, copper, and salts. In 1748, thanks to the efforts of M.V. Lomonosov, Russia's first scientific chemical laboratory was built and opened in St. Petersburg [4].

Research of M.V. Lomonosov in the field of chemistry and mineralogy served as the basis for the development of a new chemical direction in mineralogy in Russia. The scientist's works, affecting the issues of mineralogy and geology, are few in number and comprise about one tenth of all his diverse works. These include: “Mineral catalog” (1741), “First foundations of mining science” (1742), “First foundations of metallurgy or ore mining” (1742) with the addition of “About the layers of the earth” (1751-1761); “The dissertation on the birth and nature of nitrate” (1749), “A word on the birth of metals from earth shaking” (1757), “The Lowest Report to the Senate on the ubiquitous collection of samples of minerals” (1761), “The News of the Composed Russian Mineralogy” (1763) [5].

In the works of Lomonosov, many questions of mineralogy are addressed, concerning the crystalline structure and chemistry of minerals, their systematics, formation and searches. He did not clearly define the concept of “mineral”, did not make a distinction between the concepts of “mineral” and “ore”, but the scientist was one of the first to notice the main thing that characterizes the mineral most precisely—its chemical composition.

Lomonosov paid much attention to the morphological appearance of minerals, noted the characteristic forms for minerals: “Crystal figures, in which ores are present and sometimes pure metals ...” [6], described pyrite in the form of “golden-colored cubes”, antimonite with “thin rays”, spinel “similar to the octahedron's angular shape”, etc. The scientist pointed out the importance of studying the crystallographic forms of minerals for their diagnosis, sought to introduce exact mathematical and physical methods for the study of crystals. The correct geometric shape of the crystals of many minerals was considered by Lomonosov not only as an external feature, but also as a result of their internal structure. One of the basic laws of crystallography, the law of constancy of angles, was improved and the applied goniometer was first applied to measure angular quantities.

On the basis of the created atomic-particle theory, Lomonosov established the connection of the external form of crystals with their internal structure and explained the “infinite variety of bodies”, physical and chemical properties of minerals depending on the properties of the corpuscles and their “mutual union”. If the description of the external characteristics of minerals was carried out by a scientist at the level of his time, then the study of the internal structure of crystals on the basis of “corpuscular philosophy” and the determination of the physical properties of minerals (morphology, hardness, specific gravity, flexibility, etc.) depending on it was far ahead of that period of time and in many ways anticipated the ideas of modern mineralogy, crystallography and crystal chemistry.

In many works of the scientist, the idea of introducing exact methods of chemistry and physics into mineralogy and the necessity of connecting the physical attributes of minerals with their internal structure and chemical composition goes as the red line. He interprets chemistry as the science of changes and transformations of bodies: “Chemistry is the science of changes occurring in a mixed body, because it is mixed ...” [7]. This definition is close to the modern concept of chemistry—the science of substances and their transformations.

Lomonosov's research in the Chemical Laboratory of the Academy of Sciences laid the chemical-analytical direction, consisting of a qualitative and primitive quantitative analysis of metals, minerals and ores. To a greater extent, native metals and ore minerals were studied, since mineralogy was most closely associated with metallurgy.

The scientist personally worked as an experimenter, conducting many chemical experiments and studies. In addition to analyzing ore minerals, ores and salts, he performed numerous experiments on the manufacture of compositions for colored glass, porcelain, and discovered the secrets of making smalt of any color and shade.

Lomonosov investigated the dissolution of metals (iron, copper, zinc, silver, lead, mercury) in acids; salts in water, and for the first time made an important conclusion (ahead of Lavoisier by 40 years) about two types of dissolution: the dissolution of metals in acids occurs in a different way
compared to the dissolution of salts in water. Of non-metallic minerals he mainly studied salts, alum, vitriol, nitrate, sulfur and amber. In chemical studies and to determine the shape of crystals formed during reactions, the scientist was one of the first in our country to use a microscope, the design of which was improved by using a series of lenses mounted on a copper plate.

Thus, in Russia from the middle of the XVIII century, there was an increase in chemical techniques in the study of minerals, i.e. along with descriptive mineralogy, another direction arose—mineral chemistry—and, as V.V. Tikhomirov noted, “One of its founders was M.V. Lomonosov, whose works of 1740-1760 became the basis of this new chemical direction in mineralogy” [8].

Lomonosov laid the chemical study of minerals using qualitative and primitive quantitative analyzes. Along with chemical analyzes, physical experiments were carried out to study minerals in order to "make it easier to recognize the hidden nature of bodies". The scientist considered the specific gravity determined by hydrostatic weighing to be one of the main characteristic properties of minerals. He designed physical devices: a viscometer for studying the viscosity of a liquid by the drip method, a refractometer to determine "refraction of light rays passing through liquid matter" and the dependence of the refractive index of transparent bodies, including crystals, on their chemical composition; a “catoptrix-diopter incendiary tool”, the set of mirrors and lenses of which using sunlight was used to obtain high temperatures for melting crystals, as well as a “grinders” for studying the hardness of stones.

To carry out observations of crystallization processes and other chemical reactions under pressures above atmospheric and at higher temperatures, Lomonosov improved the steam boiler of the French physicist D. Papin. This "Papin's machine" was a prototype of a modern autoclave.

One of the first scientists in Russia had the idea of synthesizing minerals, artificially obtaining salts, a number of ore and other minerals; he conceived the laboratory synthesis of many minerals, including quartz and diamond, the technical conditions for the reproduction of which were impossible at that time. He was engaged in the artificial production of crystals and conducted a number of laboratory experiments on growing crystals of nitrate and other salts from solutions. With his experiments on artificial crystal growth, he contributed to the establishment of experimental mineralogy.

The scientist covered various issues of mineral formation, including deposition methods and sources of mineral matter, and paragenetic associations of minerals. The formation of vein deposits occurred, in his opinion, from "strong shocks and eruption from fire-breathing mountains". Lomonosov paid special attention to the ore veins and gave a term “ore vein” that is close to the modern definition as a crack in the rocks made by a mineral substance. Ore cracks were filled in two ways: ore minerals due to endogenous “vapors” from “underground sulfur ignition”, and vein minerals due to deposition from surface mineralized waters. Lomonosov noted the migration and recrystallization of ore minerals, the formation of crystallized ore and non-metallic minerals in the voids of the veins, he treated the precipitation and crystallization of them from solutions, like salts. The complex configuration of “metal veins”, branching, pinching out, displacement by their discharges and the formation of different mineralization products in the veins have been repeatedly noted in the works of the scientist. The origin of the stratiform deposits of copper schists—fletz ores—explained the deposition of layered rocks from water pools, which subsequently, under the influence of "underground fire" and mineralized "viscous" water, underwent a number of changes and hardened.

Lomonosov delved into and gave initial impetus to the initial development of the problem of mineral paragenesis. The scientist characterized the modern term “paragenesis” with the expression “born with ...” or simply described aggregates of co-formed minerals. There are many examples of the description of mineral paragenetic associations mentioned by Lomonosov: bismuthine with galena and pyrite, antimonite with pyrite, quartz and fluorite, cassiterite with quartz, etc. He described the destruction of the primary outcrops of gold-bearing veins and the formation of alluvial gold with the preservation of mineral splices of gold and quartz.

Based on the regular communities of minerals, he formulated search features for vein deposits, some of which have not lost their significance even now. He was given one of the first mineralogical
classifications, in which, along with the external attributes of minerals, their chemical properties were taken into account, and about 80 minerals were described. Despite the shortcomings of taxonomy, it can be attributed to imperfect chemical classifications.

3. Conclusion
The period from 1740 to 1790 is the beginning of the design of sciences: mineralogy, crystallography, chemistry. Descriptive mineralogy and crystallography dominated at this time. Minerals were recognized by external signs: color, gloss, fracture, hardness, etc. Lomonosov’s writings highlighted many questions of mineralogy regarding the crystal structure and chemistry of minerals, their systematics, formation, and searches. The concept of “mineral” was not clearly defined by scientists, there was no separation between the concepts of “mineral” and “ore”, but he was one of the first to notice the main thing that characterizes the mineral most clearly—the chemical composition.

Lomonosov’s teaching left a deep mark in geology and had a great influence on the work of both his contemporaries and on subsequent generations of geologists and mineralogists. The scientific precepts of Lomonosov were largely accepted by his follower, Academician V.M. Severgin. In his work “A word of commendation to Mikhail Vasilyevich Lomonosov” he reflected admiration for the scientist’s deep knowledge and wrote that “the word of Lomonosov about the benefits of chemistry is full of florid beauties, so much knowledge is revealed in this science ...” [9]. The following mineralogists and chemists were followers of the scientifically-mineralogical ideas of the scientist: I.G. Lehman (1719-1767), T. Lovits (1757-1804), Ya.D. Zakharov (1765-1836) and many others. The value of Lomonosov was evaluated by Academician V.I. Vernadsky: “... all the activities of M.V. Lomonosov in the field of mineralogy and geology, ... and the results he achieved there put him far ahead of his contemporaries and scientists of the next generations” [10].

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