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Victor M. Goldschmidt, Vladimir I. Vernadsky and the Birth of Geochemistry

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Abstract. Geochemistry was founded almost simultaneously during the first half of the XXth century by V.M. Goldschmidt in Norway-Germany and V.I. Vernadsky in Russia-France. The life of these two prominent scientists is briefly described, as well as the fate of their geochemistries.

Keywords: Geochemistry – Ecology – V.M. Goldschmidt – V.I. Vernadsky – science history.

Geochemistry is now a most important, if not the most important branch of Earth and Planetary Sciences. This is notably illustrated by the success of the Goldschmidt conferences, jointly organized by the Geochemical Society (USA) and the European Association of Geochemistry, which assemble every year thousands of Earth Scientists, alternately in Europe and America.

The relations between Geology and Chemistry (hence the name Geochemistry) had been somewhat ambiguous since the early days of both disciplines. The father of modern chemistry, Antoine Lavoisier (1743-1794), who started his career as a geologist, was among the first to claim that mineralogy could not be advanced without chemistry. Another great chemist, Jöns Jacob Berzelius (1779-1848), saw no reason to separate both disciplines, making mineralogy and geology a subdivision of chemistry. In fact, these branches of science took rapidly their individuality, mainly because of the place where they were performed: open nature for geology and mineralogy, man-made laboratory for chemistry. They saw their respective development along separate lines, geology and mineralogy being reserved for naturally occurring substances, chemistry for those created by man. A somewhat flexible limit, as most substances apparently created by man already exist in nature or are found later through the progress of analytical techniques.

The turning point: the phase rule

Interestingly, a turning point occurred at the end of the 19th century, with the introduction of thermodynamics to the study of multicomponent systems. It relates physical parameters (pressure, temperature, entropy) to the conditions of formation of the different phases (minerals, rocks), defined by their chemical composition. First attempts had been done by Nicolas Leonard Sadi Carnot (1796-1832), a mechanical engineer in Napoleonic army, who thought that improving the efficiency of steam engine would be of great help to the army. Sadi Carnot published in 1824 a seminal book on the power of fire (Sadi Carnot, 1824). But he died soon from cholera, all his personal belongings or writings were destroyed by fear of contagion. This work of Carnot dealt with the theoretical analysis of heat flow in steam engines. It adumbrated what is now known as the second principle of thermodynamics. The first principle, which states the conservation of energy and defines the internal energy of a system as the difference between heat and the work exchanged by the system with its surrounding, was formulated only later in the 1830s. By the middle of the century the principles of chemical thermodynamics were then firmly established. It took twenty more years to find a possible application in Earth Sciences. This was done by a physicist of Yale university, Josiah Willard Gibbs (1830-1903), who wrote a

monograph titled "On the Equilibrium of Heterogeneous Substances", published by the Connecticut Academy of Science (Gibbs, 1874-1878). This work, which covers about three hundred pages and contains exactly seven hundred numbered mathematical equations, begins with a quotation from Rudolf Clausius that expresses what would later be called the first and second laws of thermodynamics: "The energy of the world is constant. The entropy of the world tends towards a maximum."

Among Gibbs seven hundred equations is a very simple one, named the phase rule. In a simplified form, it relates the number of chemical components (C) and mineral phases (P), depending on the degrees of freedom, namely the external variables (e.g., pressure and temperature) that can be changed independently without changing the system: $F = C - P + 2$ (2 stands for pressure and temperature). For instance, for a pure mineral phase (one component), $F = 2$, meaning that one can change both pressure and temperature without changing the system. The phase rule opened the possibility to connect chemistry (chemical components) and geology (minerals and rocks), a process which will be formulated as geochemistry. But Gibbs was an extremely rigorous man, discussing in a rather hermetic style the ultimate details of his reasoning. As a result, his writings are extremely difficult to be properly understood, and it took years before they were assimilated by fellow chemists and, even longer, by earth scientists.

The father and grandfather of geochemistry (Müller, 2014)

The first geology papers directly inspired by Gibbs theories make for many the birth of geochemistry. The best known articles were written in Norway by a young geologist, Victor Moritz Goldschmidt (1888-1947) (VMG), during the preparation of a thesis under the direction of the great petrologist Waldemar Christofer Brögger (1851-1940). The PhD thesis of Goldschmidt (Goldschmidt, 1911), dealing with contact metamorphism in the Kristiania (now Oslo) region, contains a first draft of his model. But the real publications, which clearly show the filiation with Gibbs by extending the phase rule to minerals, appeared a decade later, in a series of memoirs published by the Norwegian Academy of Sciences (Goldschmidt, 1923-1927). A complete list of V.M.

Goldschmidt publications can be found in the book by B. Mason (Mason, 1992), the most complete biography written to date (See also Glasby, 2006).

A common view in the West is that these publications mark indeed the birth of geochemistry, even if Goldschmidt himself did not use this name in his last book, published after his death by Alan Muir (Goldschmidt & Muir, 1954). But, at the same time, the name of geochemistry and a first outline of the new discipline had been published by a Russian scientist, Vladimir Ivanovitch Vernadsky (1863-1945). The most significant publication by Vernadsky is a book (Vernadsky, 1924), directly written in French after a series of invited lectures in the Sorbonne.

The key papers by Goldschmidt and Vernadsky, which brought to both authors instant celebrity, are practically contemporaneous. In a major paper published in 2014, Axel Müller attributes a distinct priority to Vernadsky, whom he called the "grandfather of Geochemistry", against Goldschmidt, the "father" (Müller, 2014). Such a conclusion is justified by the fact that Vernadsky is older than Goldschmidt by a generation, even if both died almost at the same date. Also, the work of Goldschmidt has been significantly influenced by Vernadsky. When he was a student in Oslo, the young Goldschmidt paid several visits to Vernadsky in Sint Petersburg. He exchanged with him a long series of letters (Müller, 2014), which show that both scientists, not only knew each other very well, but also that they had a mutual influence on their respective work. The first letter by VMG, written in German, is very formal, starting with "Very Honored Herr Professor" ("Hochgeehrter Herr Professor"). Goldschmidt thanks Vernadsky for having sent his publications to a young student. Then, the tone of the letters is more familiar, showing that both became rapidly good friends, especially after a visit of Vernadsky to Oslo in 1927.

In 1929, Goldschmidt was offered a professorship in Göttingen. He promptly moved to Germany with "his father, mother and the housemaid" (Müller, 2014). He continued his correspondence with Vernadsky, who then changed the language of his letters from French to German. In a letter dated June 18, 1931, Goldschmidt invited Vernadsky to visit him in Göttingen. He said that he had unfortunately no funding to pay an honorarium, but that he would be happy to have him as a guest in his

home. Vernadsky accepted gladly, in a tone which illustrates their friendship (“Sehr geehrter Herr College and Lieber Freund”, Very Honored Colleague and Dear Friend). They intended notably to discuss geochemical and biochemical problems, such as the carbon dioxide content of the oceans, the chemical composition of marine organisms, the radioactivity of geological materials, etc. (Müller, 2014). Vernadsky spent a few days in Göttingen, giving a series of lectures at the university. The correspondence continued to at least 1935, until both were taken by political problems, Goldschmidt forced to return to Norway, Vernadsky bothered by the dramatic situation in Ukraine and the coming war between Russia and Germany.

In short, “it is reasonable to propose that Vernadsky’s work initiated the turn of V.M. Goldschmidt towards geochemistry” (Müller, 2014). This does not avoid that both kept their independence, shown by the significant differences between “their” geochemistry. It can be supposed that their friendship was a way to support each other, at a time where most Earth scientists did lack the chemical background to understand the new discipline. But now comes a crucial question: how two geologists, one very young, the other somewhat older, educated as classical geologists, could know enough chemistry to understand the work of Josiah Willard Gibbs, at a time when their professors had not the necessary knowledge.

V.M. Goldschmidt’s familial situation

For Goldschmidt, who was a sort of “wonderkid” during his early years, it is clear that his chemical education was given to him by his father Heinrich Jacob Goldschmidt (1857-1937), a chemist at the Polytechnikum of Zurich (Switzerland). In fact, the familial situation of Viktor Moritz was rather complicated. Born to an unknown father, he had been adopted by Heinrich Jacob, who took great care of him and treated him as his own son. Many indications suggest that Victor Moritz biological father was a friend of the family, Victor Meyer (1848-1897). Since 1872, Victor Meyer, educated in Heidelberg and Berlin, was professor at the ETH Zürich. He was married with Hedwig Davidson, who gave him five daughters. The name of Hedwig’s father was Moritz Davidson. Then it might well be that the young Goldschmidt received his double name (Victor Moritz) from both his biological father and grandfather. Victor Meyer left Zürich shortly

before the birth of VMG, to become professor at Göttingen, then Heidelberg. But he suffered progressively from strong mental depression and committed suicide in 1897.

It can be speculated that it is because of this complicated situation that the Goldschmidt family left Switzerland, firstly to Göttingen (Germany) and finally to Oslo (Norway). Heinrich Jacob was named professor of chemistry at the local university. He remained in Norway until his retirement in 1929. The young Victor Moritz had then the education of a young Norwegian, mastering so rapidly the local language that, after few years, few could believe that he was not born in Norway. He found in Norway the ideal combination of good university education, notably under the great petrologist W. C. Brögger and, very close to his home, the ancient granitic rocks which will help him to develop his theories. His thesis work on the contact metamorphism of Oslo granites (which incidentally turned out later to be more low-pressure regional metamorphism), was defended in 1909, published two years later (Goldschmidt, 1911). Doctor at the age of 21, he wanted to have a permanent position in the local university. But his colleagues found him to be too young. Then Brögger did intervene in his favor, saying that “VMG will be known as a great geologist, even greater than me”. Not a small compliment from a person having himself a very developed ego! Then VMG received a call from Sweden, and the faculty reacted promptly, appointing VMG as ordinary professor, the youngest professor even in any Norwegian university. This honor notwithstanding, VMG left Oslo for Göttingen (Germany) a few years later, to the disappointment of many fellow Norwegians who were not far to consider the move as a passage to the enemy.

Vernadsky: Education in Paris

Vernadsky’s situation was more complicated. Born in Sint Petersburg in a wealthy Russo-Ukrainian family, V.I. Vernadsky studied mineralogy and soil science (pedology) at the imperial university of the town. In 1888, as was commonly done in Russia in those years, he visited several places in Europe, in order to do some work which later could lead to a Ph. D thesis in Russia. He first wanted to study crystallography with Professor Arcangelo Sacchi (1810-1893) in Napoli (Italia), but Sacchi was no longer active (Gumilevski, 1961).

Then he spent almost two years by the famous Paul Heinrich von Groth (1843-1927) in München (Germany), to be acquainted with the use of crystallographic instruments. The scientific work was interesting, but the life in Germany a bit too rigid for his taste. Like many young educated Russians of the time, he was attracted by the French literature and way of life. He asked Paul von Groth to recommend him to Ferdinand André Fouqué (1828-1904), Professor at the Collège de France in Paris, who was working on the theory and practice of the polarizing microscope. Fouqué answered with some delay to Von Groth recommendation, invited finally Vernadsky to come to Paris.

Vernadsky had there a very pleasant life, staying with his family in Passy. He used to walk every day to the College de France, “spending hours by the bouquinistes – library display along the Seine to find and read classical books of the French literature” (Touret & Besudnova, 2021). F. Fouqué had asked him to work on the then poorly known aluminum silicates, first of all sillimanite. He determined the optical properties of this mineral, discovering also the two other polymorphic varieties (kyanite, andalusite). He worked notably with F. Fouqué’s assistant, Alfred Lacroix (1863-1948), who would remain a close friend for the rest of his life. The work at the Collège de France included the synthesis of sillimanite, a task then considered to be almost impossible. Facilities for mineral synthesis were at the Ecole des Mines, under the direction of a great chemist and expert in thermodynamics, Henri Le Chatelier (1850-1936), who was precisely translating in French the works of J.W. Gibbs. At the difference of the friendly F. Fouqué, Le Chatelier was rather severe, not too appreciated by his students who did complain that his courses were difficult to understand. But he developed a real friendship with Vernadsky, spending hours to explain him the details of Gibbs work. The experimental work at the Ecole des Mines was very successful. Vernadsky succeeded rapidly to synthesize sillimanite (very simple, wrote he in his journal). He also identified the trend of stability conditions for the three polymorphs (low pressure for andalusite, high pressure for kyanite, high temperature and pressure for sillimanite). This was the first indication of a P-T diagram that has become today a milestone in metamorphic petrology.

Back in Russia, Vernadsky quickly used the material that he had accumulated in Paris and Munich to obtain two doctorates, one in Petrology in 1890, the other in Crystallography six years later. He was then nominated professor at the University of Sint Petersburg, considered as a leading authority in Russia. But, attached to a democracy that he has experienced during his travels in Europe, he had difficulties to support that autocratic regime of the tsar– as well as the equally autocratic communist regime after the revolution of 1917. He resigned from the Sint Petersburg in 1910, to protest the student repression. On several occasions, he was in danger to be arrested, only protected by his scientific stature. He avoided the risk in travelling outside of Moscow, notably to his real home country, Ukraine. He founded there an impressive list of institutions, e.g., the Ukrainian Academy of Science and National Library, a university in Crimea, etc. He belonged to the small group of ethnic Ukrainian who had a dual Russian-Ukrainian identity. But he also considered that his Ukrainian culture was part of the Russian Imperial culture and he refused to be a Ukrainian citizen when this was possible in 1918 (Wikipedia, English).

Vernadsky also travelled frequently to France to visit his friend Alfred Lacroix, in the meantime promoted director of the Museum d’Histoire Naturelle. He met also frequently other personalities, notably Marie Skłodowska-Curie (1867-1934) whom he advised on the places where she could find radioactive minerals. He was not impressed by the rather primitive condition of Marie Curie lab – we have much better working conditions in Moscow, wrote he in his journal (Vernadsky, 1998). In consequence, he proposed to Alfred Lacroix to settle permanently in Paris to organize an Institute for Radioactive minerals – Marie Curie’s future Institut du Radium – but his offer was turned down because he was not a French citizen!

Vernadsky was very much attached to his home country, either Russia or Ukraine, and he came always back after his voyages abroad. With his favorite student Alexander Fersman (1883-1945), he participated to an Academy of Science project to catalogue Russia natural resources, travelling through the entire country to find important mineral deposits. During these travels, he became aware of the ecological disasters that

man can inflict to nature by overexploitation or mismanagement of the agriculture. This had notably resulted in the 'Great Famine', which culminated in 1921-1922, but had already started in 1891. This dramatic experience convinced him that human activity can deeply influence natural processes, a notion which will become an important aspect of his geochemistry. During these difficult years, Vernadsky did contact his French friends to obtain some funds: Excerpt from the French journal *La Justice*, May 13, 1892: "M. Vernadsky, professor at the Moscow university, has organized in Tamboff rescue kitchens according to Tolstoï method... (He) informs the committee... that, thanks to the already received 8000 Francs, he has opened 24 kitchens for 1500 people in the region of Morchansk and Kirsavovka. These kitchens have been called "Cuisines parisiennes" and the region will be called "Région des secours français"... They are the only ones where the misera- bles starving can eat bread not mixed with herbs or earth". Moreover, Vernadsky did collect in Rus- sia another 45359 rubles with the Committee to help the hungry people. He opened new dining rooms, which fed about 5000 people. (Source Re- tonews, translated from French, see also Drob- zhev, 2016).

The second stay in France (1922-1925):

La Géochimie

In 1921, Alfred Lacroix, then Professor of the Museum of Natural History, invited Vernadsky to give a series of lectures on geochemistry in Paris. At that time, Lacroix had the status of "secrétaire-perpétuel" of the Academy of Sciences. This rather strange name, still in use today, means that the "secrétaire-perpétuel" is actually the most important person in the Academy. He runs the affairs of the Academy, stays in office for as long as he wishes, may invite people at will, while the presi- dent, who changes every two years, is more a rep- resentative person, without any real power. La- croix's laboratory at that time employed several people who showed considerable interest to Rus- sia, notably his young assistant Jean Orcel (1896-1978), who later became a major specialist in ra- dioactive minerals.

There were also people from Russia and East- ern European countries, whom Vernadsky met with pleasure. He could notably discuss with the

petrographer Elizabeth Jérémine (1879-1964), a former assistant of F.Y. Levinson-Lessing, mem- ber of the first expedition of Alexandre Fersman to Khibiny in August-September 1920. She emi- grated from Russia in 1921; the same year, she was registered as researcher in the mineralogical laboratory of the Museum, where she stayed for the rest of her life (Orcel, 2009). A very good pe- trographer, she became the favorite assistant of Alfred Lacroix, working also on meteorites with Mireille Christophe-Michel-Lévy, the daughter of Auguste Michel-Lévy (1844-1911), former com- panion of A. Lacroix at the Collège de France.

Other members of Lacroix mineralogical labor- atory came from other Eastern countries (Roma- nia or Hungary) between 1920 and 1950, e.g., François (Ferenc) Kraut (1907-1983) from Hun- gary, who discovered the first traces of meteorite impact in Rochechouart (Limousin, France) (Kraut, 1967). For some reason, France seems to have been extremely attractive for Eastern stu- dents in geology during this period. In the place where most professional geologists are educated (the Institute of Geology of Nancy, now Higher Na- tional School of Geology), almost half of the grad- uates from 1923 to 1934 bear Russian names. Vernadsky was then very pleased to stay in Paris, but after some time he felt that he had to go back to Russia. When he returned to Moscow, Vernad- sky brought back a number of mineralogical sam- ples, now kept in the State Geological Museum of the Russian Academy of Sciences (Touret and Besudnova, 2021).

In May 1922, a new invitation was issued by the Sorbonne Rector Paul Appel (1855-1930). With the blessing of the Presidium of the Russian Academy of Sciences, Vernadsky traveled to Paris from Petrograd with his wife and daughter. He went through Prague in Czechoslovakia, where his son George lived at the time and where his daughter Nina remained to study. Then, with his wife alone he spent a night in Vienna and fi- nally came to Paris through Switzerland (Vernad- sky, 1998).

Both arrived in Paris by train at the Gare de l'Est (Eastern station) on July 8, 1922, met by Al- exandra Golstein (1850-1937), a political emigrant and known writer. Alexandra took them to Passy, the place where Vernadsky had lived in 1889. But,

again, Passy was too far away from the intellectual heart of Paris, the vibrant Quartier Latin. A few days later Vernadsky rented an apartment 7, Rue Toullier, much closer to the Sorbonne (Touret and Besudnova, 2021). With his wife, he did stay there for over three years between 1922 and 1925, sometimes visiting his children in Prague (Vernadsky, 1991).

The first task of Vernadsky in Paris was to give a lecture on geochemistry every Friday at the Sorbonne, which he began in December 1922. Vernadsky impressed his audience by the quality of his French, and the lectures met rapidly with great success (Vernadsky, 1998a). He had also ample time to do scientific work, often in the laboratory of A. Lacroix at the Museum d'Histoire Naturelle, also in the École des Mines, the École de Pharmacie or several libraries, including the Bibliothèque nationale. He spent also much time discussing international cooperation within the framework of several organizations, which at this time were extremely active in Paris.

After the end of the First World War, these organizations were established to restore and develop destroyed scientific relations in Europe. The League of Nations (Société des Nations), first international organization to promote peace and international cooperation and predecessor of UNESCO started in 1920, with P. Appel as the French representative and President of the French Association. Two years later a Committee for Intellectual Cooperation was established, including Albert Einstein (1879-1955), Marie Sklodowska-Curie (1867-1934), and the philosopher Henri Bergson (1859-1941). Vernadsky had frequent discussions with this Committee. He argued for the promotion of Russian science in international scientific cooperation, and the involvement of Russian scientists in the international scientific community, both those who remained in Russia after the events of 1917 and those who emigrated abroad. In February 1923, Vernadsky met under the patronage of P. Appel with H. Bergson to discuss how Russian scientists could be better integrated into international cooperation. At the same time, negotiations were underway to establish a major Russian philosophical center in Paris (Sorokina, 2003).

Vernadsky and Bergson became close friends. They met frequently in Paris, as well as few people

strongly influenced by Bergson ideas: the philosopher and theologian Edouard Le Roy (1870-1954), or the philosopher, geologist, paleontologist and priest Pierre Teilhard de Chardin (1881-1955), who had developed a new concept about the place of man in the evolution of the Earth. Obviously, the communication between the French scientists and the Russian academician had a mutual influence on their scientific views and ideas. It led to the development of the biosphere doctrine and its transition to a new concept, the noosphere, a concept that Vernadsky would integrate into its geochemistry. The noosphere represents the highest stage of biospheric development, its defining factor being the development of human rational activities (Vernadsky, 1945).

This stay in Paris proved to be very successful for Vernadsky. He conducted a number of mineralogical and geochemical studies, the results of which were published in scientific journals in France, England, Czechoslovakia and Russia. But his major achievement was his book *La Géochimie*, based on the lectures that he had given at the Sorbonne in 1923-1924. Directly written in French, this book focuses on the classification of minerals by their geochemical properties, the concept of geochemical cycles and, above all, the role of life in the formation of the planet Earth. It was the first time that a book was devoted to a discipline which, in few years, should take a prominent position within Earth and Planetary sciences. The name "geochemistry" was used earlier, either by Vernadsky or by his student Alexandre Fersman (1883-1945), but only to describe the chemical composition of some minerals or rocks. For the first time, *La Géochimie* then developed an entirely new concept, including the role of mankind, taken as a geological parameter, in the evolution of our planet. Vernadsky had the elegance to acknowledge the long influence of French scientists in the development of his new discipline. The book is dedicated « to the memory of my dear master », Ferdinand Fouqué and, in the Preface, Vernadsky mentions « fruitful discussions with A. Lacroix, who read all the text in proofs ». He added that « (he) found in his laboratory at the Museum d'Histoire Naturelle all means of scientific work and the possibility to achieve this work ».

A second series of lectures was also prepared for printing. Having revised these materials, Vernadsky wrote on his return in Russia the

monograph *Biosphere*, published in 1926 in Leningrad, a few years later translated into English and French (Vernadsky, 1929), recently republished in an annotated and extended version (Vernadsky, 1998b). The following year *Essays on Geochemistry*, were published almost simultaneously in German (1927) and Japanese (1930) (Vernadsky, 2006). Many researchers, especially English-speaking, believe that it is more *Biosphere* that signaled the emergence of geochemistry as a new scientific discipline. But this idea does not pay justice to the fact that the name and basic concepts were already present in the earlier published *La Géochimie* (Touret & Besudnova, 2021).

In his journal, Vernadsky noted that 1924 "was one of my successes in Paris", "la Géochimie came out and was a great success" (Vernadsky, 1991, p. 136). He had also many other activities during this very successful year, notably research on radioactive minerals at the Radium Institute, the Department of Basic Research on Radioactivity, headed by Maria Sklodowska-Curie (Vernadsky, 1991). Before coming to Paris, Vernadsky was engaged in the study of a mineral named after Pierre and Marie Curie, curite, just discovered in Shinkolobwe (Congo). He was assisted by Catherine Antonovna Shamie (Chamie), (1888-1950), "an unremarked remarkable woman" (Sedova, 2013). Their joined paper was published in this golden year (Vernadsky & Chamie, 1924).

Meant for two years, the invitation of P. Appell should have ended in 1924. But a grant of 30 thousand francs from the Fondation Rosenthal, « to study the amount of living matter in the biosphere », allowed Vernadsky to extend his stay in Paris. He spent then more time studying the biosphere, resulting in more works published in France: a report on "La matière vivante dans la biosphère" (Living Substance in the Biosphere"), later reprinted in "La Biosphère" (Vernadsky, 1929) and an article on "L'autotrophie de l'humanité" (Autotrophy of the Humanity) (Vernadsky, 1925)). During all this period, Vernadsky and his wife left sometimes Paris during the summer for some vacation in the countryside. They visited notably the resort of Bourbon-Lancy, known for its sulfur springs, 350 km southwest of Paris and the town of Roscoff on the Brittany peninsula, in which a sea biological research station was located, and since 1899 a health center using sea water for treatment. Then they came back and remained in

Russia, with only a short and last visit of Vladimir to Paris in 1936, to lecture on radiology at the Sorbonne.

The Geochemistry of V.M. Goldschmidt

When *La Géochimie* was published in Paris, V.M. Goldschmidt did publish a series of papers on the laws of element distribution in the Earth, that many regard as marking the foundation of "his" geochemistry (Mason, 1992, Glasby, 2006). Written in German – VMG was working at this time in the University of Göttingen- these papers were published in the Proceedings of the Norwegian Academy of Science (Goldschmidt, 1923-1927). These papers were preceded by a publication on the evolution of igneous magmas through fractional crystallization, also published in the Proceedings of the Academy of Science (Goldschmidt, 1922). They were followed by many publications until 1938, in which Goldschmidt established the main frame of "his" geochemistry.

Among the main advances in the geosciences propelled by Goldschmidt's research during this period was the geochemical classification of the elements into siderophile, chalcophile, lithophile and atmophile elements, also related to their position in the Periodic Table. Furthermore, from the study of meteorites containing iron-nickel, troilite (FeS) and silicates he calculated the partition of the elements between metal, silicate and sulfide melts, and eventually used those data to estimate the absolute abundance of the elements. This was based on the realization/assumption that (some) meteorites provided an unaltered sample of the material that coalesced to form the Solar System.

VGM and his coworkers also stressed the importance of the atomic radius and charge of ions to explain, among other things, the compatibility or incompatibility of elements in minerals. They showed how the crystal chemistry could be described as an infinitely extended network of regularly spaced ions rather than individual molecules explaining substitutions independent of charge and valence. Furthermore, Goldschmidt calculated the element distribution of the crust based on the bulk composition of glacial clays, described the breakdown of a rock through chemical weathering, formulated the geochemical cycle of the outer part of the Earth: the redistribution of elements between the Earth's crust, atmosphere,

hydrosphere, atmosphere and biosphere and subsequently the carbon cycle. (Internet site of the Department of Geosciences, University of Oslo

https://www.mn.uio.no/geo/english/research/goldschmidt/about_goldschmidt/index.html)

Contrary to Vernadsky, who took more than 20 years to elaborate "his" geochemistry, the conception of the new discipline by Goldschmidt was very short: almost everything was ready between 1922 and 1927, the rest being mainly applications by Goldschmidt himself or by his co-workers. VMG made almost no use of the word "Geochemistry". The first time when he made use of this word was in a title of a book describing exhaustively his new discipline, published only in 1954, seven years after his death (Goldschmidt & Muir, 1954). The main reason for this delay was the political problems that he faced at the end of his life in a Europe progressively hit by WWII. In 1929, already full professor of petrology and mineralogy at the University of Oslo, he had accepted to become professor at the famous university of Göttingen. He had there outstanding working conditions, good scientific friends, was repeatedly nominated for Nobel prize (11 nominations in total, but he never got the prize for himself, leaving it to other scientists who had worked on direct consequences of his work).

Despite the good working conditions, V.M. Goldschmidt became rapidly perturbed by the political situation in the Third Reich. Issued from a Jewish family, he had not paid much attention to his faith during his youth. But the Jewish persecution by the Nazi regime led him to show openly his Jewish origin while in Göttingen. Protected by his scientific stature, he was well treated by his university. But the treatment inflicted to other non-Aryans by the Nazis led him to resign from Göttingen and return to Norway in 1935.

In Norway, VGM continued his research, publishing the ninth part of his *Geochemical Laws*, which he called his "Ninth Symphony." In it, he arrived at a table of cosmic abundances, from a combination of meteoritic and solar data, which provided the basis for later theories of the origin of the elements. "Goldschmidt's perception of the fundamental significance of meteorite compositions for geochemistry is another example of his

scientific genius" (Mason 1992). He was the director of the Råstofflaboratoriet (State laboratory for raw materials), that he had founded in the Tøyen Geological Museum in 1917. In this position, he had a key responsibility for the prospection of radioactive minerals in Norway and management of radioactive products, notably the heavy water that Norway was the only country in the world to produce in its Telemark factory. These responsibilities put him in a difficult position when Germans did invade Norway in 1940.

The Germans did respect the scientific stature of the former professor of Göttingen university, but they also made all efforts to put him on their side. They had installed in Oslo a pseudo-government under the direction of the chief of the local Nazi party, Vidkun Quisling, a name hated in Norway until today. Quisling minister of propaganda was a certain Gulbrand Lunde, who had been VMG assistant several years earlier. There is no doubt that Goldschmidt was on the side of Norway, there are many signs showing that he was actively involved in the resistance against the German invasion. For instance, he convinced the director of Norsk Hydro to sell the reserves of Telemark heavy water to the French, just before those being confiscated by the Germans. But he had also a rather complicated personality, which caused him some problems with his colleagues in Oslo.

A former student of Goldschmidt, Tom Fredrik Weiby Barth (1899-1971), who had been the director of the Geological Museum when V.M. Goldschmidt was in Göttingen but had then a prominent position in the Geophysical Lab. Washington DC, USA, decided to come back home to defend his country. Tom Barth landed in Norway a few days before the German invasion, not so well received by V.M. Goldschmidt who apparently did not fully appreciate to have by him such a high-quality scientist. VMG did only allocate a small working place to Tom Barth, a desk in the basement of Tøyen, and provided him with a minimum of financial resources. He leased him a flat in his magnificent house near Holmenkollen, which should later become Tom Barth's own house. But the flat was not cheap, Tom Barth had to sublease a room to a German, soon accused to be a spy (unproved rumor says that the accusation could have been issued by VMG himself). He (VMG) wrote also a letter which was supposed to remain confidential, but soon became known by a large

public. In this letter, VMG did compare Barth to Lunde, stating that he did prefer the second. The controversy would resume after the war, well after VMG death, with another set of rumors stating that VMG had accused Tom Barth to be an “agent double”, an accusation which could have put Tom Barth’s life in danger. These rumors again were soon proven to be totally unfounded, and they did not change the esteem that Tom Barth had for his ancient professor. After the war, Barth returned to the US to become professor at the University of Chicago. In 1949, he came back again in Norway, professor at the Toyen Geological Museum and soon one of the first world figure in Earth Sciences (e.g., the first president of the newly founded IUGS). Tom Barth was the director of my (JT) Ph D thesis in Southern Norway. I have well known him from 1957 until his death in 1971. I never heard a strong word of Tom Barth about VMG, just laudative comments about his scientific genius.

Despite all efforts that VMG had done to look cooperative with the Germans, he was soon taken by the war. He was arrested as a Jew in 1942, sent to the Berg concentration in Tonsberg, where he became seriously ill. Thanks to the intervention of Gulbrand Lunde, he was freed some weeks later, but soon arrested again. This time Gulbrand Lunde was no longer there, he had died in the meantime in a drowning accident. Placed in a group of Norwegian Jews to be sent to Auschwitz, VMG could escape on the pier, freed by the policeman, named Karl Marthinsen, who did survey the group. Who has persuaded Karl Marthinsen to free VMG is not precisely known. It was said at this time that the decision could have come directly from Berlin. But this is not likely, for obvious time reasons. More plausible is the action of a watchmaker from Tøyen, who came on the pier to help VMG and who knew Karl Marthinsen, having been with him in the military few years ago. VMG was then exfiltrated to Sweden by another policeman who told later that he was ordered to carry a loaded gun, with the order to shoot down VMG at the first sign of contact with the Germans.

In Sweden, VMG was offered again the Swedish citizenship. Like in preceding occasions – the first one when he had been nominated in Oslo, the second after his resignation from Göttingen-, he refused, not wanting to be the only Norwegian academician who could benefit of this privilege when his nation was still at war. Then he was

transported to Scotland, by a British intelligence unit (Gladby, 2006).

Despite much information transmitted to the Allies about the situation in Norway and the state of German science on radioactivity, his former contacts with Germany made VGM somewhat suspect to British and fellow Norwegians. A policeman who had helped him to go to In Scotland, VGM was maintained in a semi-isolation in the Macaulay soil Institute in Aberdeen, assisted by Alex Muir, who helped him to finalize his book. At the end of the war, he wanted to go back to Norway, which he did in June 1946, not welcomed again by some of his countrymen. He had been seriously ill in Scotland, treated in hospital for heart disease. He had apparently recovered but died suddenly one year later from cerebral hemorrhage, only a few days after a cancer operation, most likely for malignant melanoma. He also had a blood disease causing elevated levels of hemoglobin.

Even though his scientific achievements were already known in the entire world, VMG death occurred in almost complete anonymity. None of his colleagues was present at his funeral. He had prepared three urns in olivine for the ashes of his parents and himself, which were placed in a chapel of the Vestre Crematorium in Oslo. But, after some time, a new law required that dead persons should be officially buried. Goldschmidt family had no descendants, a letter was sent to the University asking for a decision, without proper answer. The university did not want to take the responsibility of a grave. The director of the Geological Museum in Oslo, Johannes A. Dons (1920-2021) was an excellent structural geologist, but he failed to identify the genius of VMG (Dons, 2000). He did contact the Mosaic Congregation in Oslo, but VMG had been circumcised in Göttingen, they could not find his name in their papers. Finally, the urn which should contain the ashes was kept for several years behind a radiator in Tøyen Geological Museum. But when it was opened few years later, it was found to be empty. Nobody knows for sure where the ashes could be, most likely in the ground near the crematorium. Then, the three urns were placed in anonymity in the memorial grove for unmarked graves at the Vestre Gravlund cemetery (Siw Ellen Jacobsen, journalist, Oct. 30, 2020). More than 70 years later, there are still no street, square or place named after V.M. Goldschmidt in Norway, but well a V.M. Goldschmidt

Strasse in Göttingen, the street of the new Mineralogical Institute of the university. Conversely, dozens of places are named after V.I. Vernadsky in the former Soviet Union, including the famous Vernadsky Geochemical Institute and Museum in Moscow, a prestigious street and metro station (Prospekt Vernadskogo), also in Moscow, the National Academy and Library in Ukraine, and many others.

VGM book on geochemistry, completed and edited by Alec Muir, was only published in 1954, seven years after his death (Goldschmidt & Muir, 1954). At this time, geochemistry had already escaped from his author, developed in US universities or in Finland (Rankama & Sahama, 1950). The discovery of advanced instruments for measuring trace elements or isotopes, many of them conceived or developed during the war, has greatly enlarged the scope of the discipline, which will rapidly become one of the most important branches of Earth and Planetary Science. Most developments took place in the US, in the best universities of the East- or the West coast, to spread rapidly over the entire world.

V.M. Goldschmidt and V. Vernadsky geochemistries

Relying extensively on thermodynamics, geochemistry according to V.M. Goldschmidt is purely chemical. It aims at a better understanding of the conditions of formation of rocks and minerals, first of all to obtain more economical resources. The Earth is seen as an inexhaustible reservoir, which would restore by itself any damage caused by the exploitation. In this respect, it must be recognized that geochemistry has been extremely successful: estimated oil reserves, for instance, only assumed to be few 10's years in the sixties, have been systematically enlarged by new discoveries. But it was also progressively realized that overexploitation was not without danger, being the source of the environmental problems that we know today. This risk was much earlier foreseen by V. I. Vernadsky who, trained as a pedologist, had warned in his book that human activity could modify natural processes and, if not properly controlled, lead to planetary disasters. Vernadsky had been much impressed by the great famines of the years

1931-1932, which caused millions of deaths in Ukraine and in the neighboring countries. In this respect, he can be credited of the invention of ecology.

Sadly, his message was ignored, including in his own country. Like the Western World, Soviet Union was under high pressure to find natural resources, which it did with remarkable success. Despite his scientific prestige, Vernadsky was not able to influence the politics of the communist regime. His main disciple was Alexandre Fersman, who had a personal relation with Lenin, but less worries about any possible environmental problem. Foolish initiatives, such as the use of atomic bombs to create underground cavities in the Kola peninsula, drying out the Aral Sea in Kazakhstan, were responsible for the greatest ecological disasters known on Earth in modern times.

After WWII, the fate of geochemistry according to Goldschmidt or Vernadsky was quite different. When he did his lectures at the Sorbonne university, Vernadsky was quite popular in France, elected to the Academy of Science at the evening of his last lecture. But this was more a success of curiosity, French geologists at this time did lack the physico-chemical background to understand fully his message. Then, the cold war made a drastic separation between the East and the West. Goldschmidt geochemistry exploded in the US, and a new generation of French geochemists, educated in American universities, claimed when they returned to their home country that they had discovered a discipline which had been discovered in Paris more than 30 years ago. In France, the name of Vernadsky was almost forgotten, only remembered by few tenants of the Gaia hypothesis, more considered as philosophers than real scientists. Important developments of the Vernadsky school, *e.g.*, the work of D.S. Khorjinskii on metasomatic processes (Khorjinskii, 1970) were either ignored, or not understood at their real importance. The situation gradually changed during the last 20 years or so, mainly under the pressure of ecological problems. It is now realized that both Goldschmidt and Vernadsky must be credited of the discovery of geochemistry, also that several problems that our planet faces at present could have been avoided by adhering earlier to the rules that he had defined.

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(1922-2019), who lived with VGM in Sweden and remained very close to him until his death.

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