# *Appendix A*

## BIOGRAPHIES/MEMORIALS BY P. ROSBAUD, C. E. TILLEY, AND O. HASSEL

### Victor Moritz Goldschmidt (1888–1947)*

PAUL ROSBAUD

"THE BASIC problem of geochemistry," said Victor Moritz Goldschmidt, "is to determine the quantitative chemical composition of the earth and to find the laws which underlie the frequency and distribution of the various elements in nature."

During the nineteenth and early twentieth centuries attempts were made, mainly by chemists, to collect the chemical and physical-chemical data relating to mineralogical and geological chemistry. In Switzerland, Schoenbein coined the name "geochemistry"; in Germany Carl Gustav Bischof published, between 1848 and 1854, his famous treatise on "Physical and Chemical Geology" which presented the chemical knowledge of his time. The great Berzelius in Sweden did much to elucidate the chemical genesis of minerals and rocks, and at the beginning of the century J. H. van't Hoff laid the foundation of the physical chemistry of salt minerals. The greatest contributions came from the work of the American petrologists F. W. Clarke and H. S. Washington. Modern geochemistry, however, had its origin in Oslo. The laws which determine the geochemical distribution of the elements were postulated by V. M. Goldschmidt from 1917 on.

Goldschmidt was born on 27 January 1888, in Zürich. His father, Heinrich Jacob Goldschmidt, was a distinguished physical chemist who came from Prague which was then, of course, part of the old Austro-Hungarian monarchy. His mother was Amelie Köhne, and Victor Moritz was their only child. In quick succession his father became professor in Amsterdam, then Heidelberg—where V.M. received his early schooling and in 1905 (*sic;* probably 1900) he was appointed professor of chemistry, succeeding Waage at the University of Oslo (then Christiania), at that time the only university in Norway. Famous for its tradition in the mathematical sciences, Oslo was also famous for its school in the earth sciences. V.M. matriculated in 1905 to study mineralogy, geology, inorganic and physical chemistry, and came under the inspiring influence of the great W. C. Brøgger, whom he soon equaled in the importance of his geological and petrological work. Except for the winter terms of 1908 and 1911 when he worked under F. Becke in Vienna and P. von Groth in Munich, he finished his studies in Oslo and obtained his doctor's degree in 1911. After two years as a lecturer he was appointed, in 1914, at the early age of 26, full professor and director of the Mineralogical Institute of the University of Oslo.

By then, shortly before the outbreak of World War I, the first scientific harvest was brought in. His earliest paper on the pyroluminescence of quartz[1] was published when he was a first-year student. The main work of this period, which has since become a classic, was his 480-page study on the contact metamorphism of the Oslo region[2] published in 1911. Throughout this monograph Goldschmidt applied physical-chemical considerations to geological problems, rightly regarding the whole planet earth as one single physicochemical system.

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It was perhaps the first time that, by Goldschmidt's mineralogical phase rule, the applications of Nernst's heat theorem and the law of mass action on complex systems of rocks, mineralogy have come of age as an exact science.

It took Goldschmidt eight years to complete the fundamental investigations that followed his work on contact metamorphism: an intensive geological-petrographical study of regional metamorphism of the mountains of southern Norway.[3]

Long before war broke out the Goldschmidt family had become Norwegian citizens. When the general situation in the neutral countries deteriorated, and after the intensified U-boat warfare, Norway was largely cut off from overseas; sources of raw materials were badly needed. The result was that in 1917 the Norwegian government decided upon thorough research into the mineral resources of Norway, and entrusted Goldschmidt with this task. He became chairman of a Government Commission for Raw Materials and director of the Raw Materials Laboratory. This work, which was directed entirely toward practical ends during the war, was continued afterward along general lines from which developed a new branch of science, geochemistry, which from the theoretical and the practical point of view is of the greatest importance. Several schools of geochemistry existed already and a mass of material was available. Apart from the American school, pre- and postwar Russia had produced some outstanding personalities such as W. J. Vernadsky, who did pioneer work notably in biogeochemistry, i.e. the frequency and distribution of elements in plants and animals. The work of today's leading expert on the origin of primitive life, Oparin, has its roots in Vernadsky's earlier work and is mainly a geochemical and biogeochemical complex of problems. There is also the school of the other leading Russian geochemist, A. E. Fersman, who died during the last war. Unfortunately his four-volume treatise on geochemistry has never been translated. However, the fundamental laws and principles underlying frequency and distribution of elements—the basic problem of geochemistry—were developed by V. M. Goldschmidt in Oslo between 1920 and 1928 and, when he was in Göttingen, by systematic research into the geochemistry of individual elements. That Russia alone has produced some 25,000 geochemists after the war gives some idea of the importance of modern geochemistry.

With an excellent team of co-workers, and with great energy, every conceivable method of chemical and physical analysis was used for the accumulation of data for a formidable task. Analytical methods had to be checked and adopted or new ones developed; carbon arc optical spectrography was developed; chemical analysis by characteristic X-ray spectra, already used by von Hevesy and by Assar Hadding in Sweden for geochemical purposes and mineral analysis, proved very useful; plans were also made by V. M. Goldschmidt for the construction of a mass spectrometer for the determination of the mass ratio of isotopes. The outbreak of the Second World War prevented Goldschmidt from introducing this instrument to geochemical research. Today mass spectroscopy has become a widely used tool in geochemical laboratories.

One of the methods extensively used by Goldschmidt was the analysis of crystal structure by X-rays, the great discovery of Max von Laue, and of W. H. and W. L. Bragg. The use of this method broadened the original views considerably, and almost as a byproduct a new scientific discipline, crystal chemistry, was created.

One of the principal problems in the history of the earth that Goldschmidt approached is the partition of the chemical elements during the geological evolution between gas and coexisting liquid phases, the subsequent crystallization of these liquid phases, the subsequent crystallization of these liquid phases, of molten iron, iron sulfides, and fused silicates, and the distribution of the chemical constituents in these phases. According to their tendency to enter one or the other of these phases, the elements could be classified into siderophile (metal melt), chalcophile (sulfide melt) and lithophile groups (silicate melt). A fourth group, the atmophile group, includes those elements which in pregeological times differentiated into the primordial atmosphere. It is of great interest that the distribution of the chemical elements among the three phases (iron, sulfide, silicate) is closely related to their atomic volume and the structure of their electronic shells.

The main controlling factors during these stages of differentiation are the chemical affinities of the various elements toward oxygen and sulfur and their latent heat of vaporization as compared with the affinity of the most common terrestrial heavy metal, iron. Goldschmidt took as a measure of these affinities the free energy of oxidation per gram atom of oxygen of the lowest oxides of the electropositive elements and the corresponding data for their sulfur compounds. Elements which are extremely rare in the earth crust—the lithosphere—are gold, the elements of the platinum group, and also nickel, cobalt, and germanium. They can be expected in the iron phase, the siderosphere. On the other hand the alkali and alkali-earth elements, silicon, aluminum, titanium, elements with a higher free energy of oxidation than iron, will, in the primordial differentiation, have concentrated in the outer silicate crust of the earth. Incidentally, it is known that the siderophile elements—gold, platinum metals, etc.—enter fused iron and iron alloys and are thus found as by-products in iron and steel works. The other analogon in metallurgical practice is the concentration of lithophile elements in the slag.

The next step after the primordial differentiation is the cooling of our planet and the crystallization of the silicate crust, a process which is still going on in rock formation from volcanic magmas.

Goldschmidt attacked the problem of finding the general laws and principles of geochemistry "from the viewpoint of atomic physics and atomic chemistry and to find out the relationships between the geochemical distribution of the various elements and the measurable properties of their atoms and ions." He soon discovered that the principal factor regulating the entrance of atoms and ions and the distribution of the rarer elements in the crystalline phases of igneous and metamorphic rocks was the size of the atoms and ions and not their weight. During the gradual crystallization of liquid solutions, those atoms or ions of rare metals are caught in the already existing three-dimensional lattice which, because of their size, fit into this lattice. Those atoms and ions which are either too small or too big to be caught remain in the liquid. This idea led to the discovery of the fundamental relationship between crystal structure and chemical constitution:

> The structure of a crystal is conditioned by the numerical proportions, the proportion of size and the properties of polarization of its ultimate particles, and not only the structure but also other important properties of crystals, such as hardness, solubility and melting temperature, could be predicted from the properties of the atoms, and so, in the course of our geochemical investigations, the foundations of modern crystal chemistry were laid. These relationships were not limited to crystalline phases, but applied as well to the properties of solidified glasses . . .

Until then crystallography was for the mineralogist and the practical chemist: as Goldschmidt wrote, "a purely descriptive auxiliary science which made possible the recognition and distinction of crystalline materials whether they were minerals or technical products." Goldschmidt with his excellent team of co-workers—T. F. W. Barth, G. Lunde, I. Oftedal, L. Thomassen, W. H. Zachariasen and others—embarked on a hitherto unsurpassed systematic series of X-ray studies. In 1926 the atomic and ionic sizes, i.e. the radii of the greater part of the chemical elements in their different stages of electrical charge or ionization, were determined. Goldschmidt was now in a position to predict in which minerals, rocks, or ores a certain element could be found—an achievement equally important scientifically and practically. To give only one example from innumerable cases which has been proved: nickel and magnesium have as divalent positive ions the same radius of 0.78 Å; this is the reason why nickel is found in magnesium silicates of igneous rocks, and the percentages of both follow each other closely. Goldschmidt could soon predict the sequence of fractionated crystallization, taking into account the electrostatic forces between the positive metal ions and the negative silicate ions.

However, there are additional forces which support the electrostatical attraction of the ions in the crystal frame work, i.e. van der Waals forces, polarization forces, and the electron pair forces. They result in a measurable contraction of the lattice which is highest in the case of nickel orthosilicate, followed by magnesium and then by iron (ionic radius = 0.83 Å). Nickel, in the fractionated crystallization from magmatic or other solutions, is the first, and iron the last to enter the mixed crystal. The concentration of nickel in magnesium-orthosilicate is sometimes of economic importance.

Goldschmidt could further predict the sequence of crystallization in cases of elements of the same size and practically the same ionic radius, but different electrical charge. If a divalent element, such as magnesium, is the main constituent in a crystal in contact with a saturated solution containing, as minor constituents, a trivalent element, such as scandium, and a monovalent, such as lithium, then, owing to the excess of electrostatic attraction, the trivalent scandium is preferentially built into the crystal—"captured"—whereas the univalent element lithium, owing to its smaller electrostatic charge, is only "admitted" to the lattice toward the end of the crystallization period. We understand now that scandium is not nearly as rare as it was formerly considered, but is a frequent constituent of many igneous rocks, especially magnesium silicates.

The problem of ionic substitution in minerals, which has occupied the mind of every mineralogist, was simply and elegantly solved by Goldschmidt's fundamental laws of crystal chemistry.

The chemical and geochemical behavior of elements with the same valency and almost the same ionic radii is of especial interest. The classical examples are the pairs aluminum/gallium and zirconium/hafnium. The trivalent gallium (radius = 0.57 Å) is "hidden" in aluminum (radius = 0.62 Å) and practically every aluminum mineral, every bauxite contains up to 100 g of gallium per ton of aluminum. It accompanies aluminum through all the stages of industrial manufacture, and can be detected in practically every aluminum alloy. The tetravalents zirconium and hafnium have the ionic radii Zr = 0.87 Å; Hf = 0.86 Å. It will be remembered that in zirconium minerals von Hevesy discovered hafnium, the existence of which was predicted by Bohr's atomic theory. Goldschmidt called this hiding of a rare element in another "camouflage." The most famous example of camouflage is found in the rare earth elements, and the celebrated elucidation of the geochemical and chemical behavior of this fascinating group of elements, closely related to their ionic radii and valency, is one of the most magnificent achievements of Goldschmidt's work.

In his monumental work *Geochemische Verteilungsgesetze der Elemente,* I–IX,[4] Goldschmidt laid down the fundamental laws of geochemistry and crystal chemistry. These 600 pages contain the life work of one who, more than anyone else, has laid in two branches of science the foundations on which later generations will build. Nos I–VIII contain the result of his work in Oslo, IX (the "ninth symphony" as he used to call it) originated from one of his happiest periods of life in Göttingen. No. VII contains the famous laws of crystal chemistry and No. VIII the relations between the structure and properties of crystals. One of the problems Goldschmidt approached in the latter communication are the factors influencing the hardness of crystals. Based on earlier work by Reis and Zimmermann, and by Friedrich, Goldschmidt systematically—supported by hundreds of investigated substances—extended our knowledge by showing how the hardness of a crystal was determined by the interatomic distance, the valency, and the structure type. Goldschmidt, however, did not stop here and went on to the question of whether it is possible to "construct" crystals of certain well-defined and desired properties, such as hardness, melting point, solubility, optical refraction, chemical reactivity, etc. Unfortunately this work on "model structures" of crystallized silicates and silicate glasses has remained comparatively unknown in the English-speaking world, as it was published in a journal not easily accessible (*Zeitschr. für technische Physik,* 1927). In this paper, readers will find the scientific basis of a problem of quite fundamental importance—how to construct solid materials of certain physical, chemical, and mechanical properties.

The year 1929 was a decisive year for V.M. (as he was affectionately called). In that year he was invited to join the faculty of natural sciences of Göttingen as full professor and head of the Mineralogical Institute. Other invitations from foreign universities had come to him, and more than one university was anxious to obtain the collaboration of the recognized leader in his field. Stockholm had tried previously; V.M. decided in favor of Oslo. A few years before he went to Göttingen the University of Munich had planned to appoint V.M. to the vacant chair of Paul von Groth. The failure of this proposal is a typical and ominous sign of the political influence of a small group of professors in the town which later became the hotbed of Nazism. Unfortunately at the decisive meeting of the faculty a number of politically moderate and reliable people were absent, believing that Goldschmidt's appointment was already decided. As a result the invitation was turned down because "We already have one Jew at the Faculty." In protest against this racial discrimination, the "Jew at the Faculty" resigned. He was Richard Willstätter, Nobel Laureate, and one of the greatest organic chemists of his time.

In view of this experience, V.M. may have been reluctant to accept an invitation from another German university. However, Göttingen was not Munich and, in the tradition of its great permanent Under-Secretary Althoff, the Prussian Minister of Education, treated V.M. with the greatest courtesy and, fully aware of the great importance of this appointment, agreed to all V.M.'s wishes. It is said that after a meeting for Goldschmidt's official acceptance and final decisions the very dignified Under-Secretary and his advisers joined in a dance of joy.

Goldschmidt, with his father and their Norwegian housekeeper, Frökken Marie Brendigen (his mother had died shortly before), moved to Göttingen where V.M. bought a house in Wagnerstrasse. On arriving in Göttingen, father and son found the town "dressed over-all"—not to greet the distinguished scientist, but to honor Colonel Düsterberg, the leader of a somewhat nationalistic organization of soldiers called "Stahlhelm" (the Steel Helmet). The Stahlhelm was harmless compared with those organizations that replaced it after 1933; Colonel Düsterberg, being only "partly" Aryan, was forced by the Nazis and S.S. to resign. Nevertheless, it gave the Goldschmidts an ominous foretaste of things to come.

There was a galaxy of eminent men of science in Göttingen at that time. The mathematical tradition—uninterrupted from the days of Gauss—was carried on by David Hilbert, Courant, Landau, and others; the organic chemist and Nobel Laureate Wallach was living in retirement and his successor (also a Nobel Laureate), A. Windaus, of cholesterol fame, was at the height of his career. Another Nobel Prize winner was Zsigmondy; the physics department was headed by the triumvirate James Franck, Max Born, and W. Pohl—after 1933 the first two, both Nobel Laureates, became "unbearable." Prandtl, one of the founders of modern aerodynamics, was one of Göttingen's great men; so was G. Tammann, the physical chemist who was still very active after his retirement, and who was succeeded by A. Eucken. The zoologist Kühn and the astronomer Kienle became great personal friends of the Goldschmidts. There was also a young generation, many of whom have since become world-famous.

The few years before 1933 were perhaps the happiest in Goldschmidt's life. In Oslo he was something of a lone wolf; in Göttingen he not only inspired his own students and colleagues, but drew inspiration from them all—the physical chemists, the inorganic chemists, the physicists, astronomers, and biologists. It was an almost ideal cooperation among scientists of every branch, and nobody sat in an ivory tower, anxiously guarding the results of his own work from intruders. In addition there was a constant exchange of ideas with foreign visitors and guests.

The Mineralogical Institute was housed in a former school which was adapted according to V.M.'s requirements. One wing contained the lecture theater, students' working rooms and laboratories, and the teaching collections of crystals, minerals, and rocks. The teaching department was connected to the third-floor research wing by a wide corridor in which magnificent specimens of minerals were displayed. There, a group of young and very able scientists set out under the direction and guidance of V.M. to study the geochemistry of individual elements. The laws which govern the distribution of elements were postulated in Oslo. They were now applied to the systematic survey of a large number of elements.

This period between 1929 and 1935 or, to be more precise, 1933, was the happiest epoch in the lives of V.M. and his aging father H.J. There the lonely man found not only devotion of his collaborators, which he had enjoyed in Oslo, but also the warm friendship and admiration of his colleagues.

In those pre-war days Goldschmidt was a heavily built, stout man, shy and often difficult to approach. He had an almost old-fashioned courtesy which could change to an outspoken but equally courteous frankness in scientific and other arguments. Shortly before he died he told me a story which is a clue to his strange personality. When his father moved to Heidelberg young V.M., who was about six years old, attended a private school. His mother had impressed upon him that he must always be polite and also tell the truth, however disagreeable. After a few days at his new school, the headmaster, a big man with a black beard and of alarming appearance, asked young V.M. how he liked the school, and ended by saying: "I hope we will become good friends. Do you already like me?" Aware of his mother's admonition, after a moment's pause V.M. replied: "Nicht so besonders, Herr Göckel" (not particularly, Sir).

As well as this "truthful politeness" which is found in some of his polemics and in many of the discussions after scientific meetings (not always to the delight of those concerned), he had a grim and sarcastic sense of humor, and was very quick-witted. In all scientific and personal affairs he was completely sincere, honest, and incorruptible. There was no room in his department for anyone who did not measure up to his own scientific and moral standards, nor for sloppy and untidy workers. He was enthusiastic about new, exciting, scientific results wherever they came from; but his criticism of unsound or too highly publicized work could be devastating. He had a certain naive streak of vanity, and he was easily hurt if insufficient credit was given to his work. I well remember his reaction to a long review article on some fundamental problems of geochemistry by a well-known chemist, in which only one reference was given to a paper by V.M., and that, on a minor subject. However, this was after 1933 and the author had undergone a color metamorphosis to brown—the Nazi color. It is only fair to emphasize that in the case of V.M.G. this was one of the rare exceptions. Almost all of his collaborators and colleagues stood by him in the dark days after 1933. Only one case is reported in which a younger and presumably ardent Nazi scientist dared to refer to V.M.'s name in the Nazi prescribed form—V.M. (Israel) Goldschmidt—in the Nazi-sponsored *Zeitschrift für die gesamte Naturforschung* (in the Germany of those days nicknamed "Zeitschrift *gegen* die gesamte Naturforschung").

He was by nature a pessimist and, partly perhaps because of his Jewish origin and of the anti-semitism which he had experienced from his childhood on, he occasionally suffered from a feeling of persecution. This was why he did not readily trust people until he knew them well and also why he was so responsive to genuine overtures of friendship. His kindness and generosity were unfailing, even to people unknown to him personally. He was a real animal lover and his garden was almost a bird sanctuary. There is the story about his learning the cat language, an attempt which came to an abrupt stop when he was attacked by a large tomcat to whom he had, apparently, unwittingly been extremely rude. The household, in addition to its human inhabitants, consisted of the famous dachshund "Bazi"—which tyrannized father and son; three squirrels demanded and received a home in the bathroom, a toad hibernated in the cellar, and a family of bats resided in the loft. Each had a name, and the toad shared his with a well-known and not too endearing character in Göttingen. One of the squirrels was named Parsifal ("because he was indescribably stupid") another was Richard ("Weil er so stark riecht"), but the most notorious was Magdalena, who came to a sad and untimely end. V.M. gave a birthday party for Bazi and several dog guests were invited to share the birthday cake. In the excitement, Bazi concluded that on this special day everything was permitted and ended the feast by devouring Magdalena.

Only a few of his devoted assistants and collaborators in Göttingen can be mentioned—most of them are today heads of university departments: F. Laves, Zurich; Th. Ernst, Erlangen; H. Hauptmann, São Paolo; W. v. Engelhardt, Tübingen; H. Witte, Darmstadt; R. Mannkopff, Göttingen; C. Peters, Vienna.

The scientific harvest of this short Göttingen period was particularly rich. From 1930 to 1935 Goldschmidt published an inspiring series of papers on the geochemistry of rarer elements. In each case terrestrial material from all parts of the world was analyzed; meteoritic matter was also included. New analytical methods were developed, such as the cathode layer technique which proved to be one of the most valuable methods for the detection of elements dozen to and below 0.01%. It is impossible to condense into a few paragraphs the results of well over two dozen papers, dealing with the geochemistry of the alkali metals, nickel, the noble metals, germanium, gallium, scandium, boron, arsenic, and selenium. In almost every case the abundance of the elements in the earth's crust, in meteorites, and in stellar atmospheres were investigated. One typical example is the investigation by V.M. of the geochemistry of germanium and its occurrence—with other rare elements—in coal and coal ashes.

This element is distributed in silicates of the upper lithosphere, owing to the similarity of the ionic radii of Ge and Si. It is also present in iron meteorites, and Goldschmidt found striking concentrations of it in the ashes of certain coals. A preliminary spectrographic analysis of the ashes of the boiler in V.M.'s institute and the soot in the chimney led to a systematic investigation of the geochemistry of coal ash. The highest amount—1.6% $GeO_2$—was found by V.M. in ash from samples of Northumberland coal. Still higher amounts (up to 9%) were found later in lignites from the District of Columbia, and in certain Russian coals.

The biochemical, or rather biophysical, mechanism of the enrichment of this and other rare elements—boron, arsenic, beryllium, cobalt, nickel, platinum metals—is still far from clear and needs further elucidation. Among those elements most highly concentrated in coal ash is arsenic. V.M. thought that one of the causes of the professional disease of chimney sweeps, skin cancer, may be the high content of arsenic in soot and flue dusts. It should be noted that petroleum shows a still greater affinity for trace elements than coal, and certain ashes of petroleum are used as a vanadium ore containing up to 70% $V_2O_5$.

Some thirty years ago the metallurgy and the industrial uses of minor elements were practically unknown. It did not "pay" to recover rare elements or to develop industrial uses for these. Today, thirteen years after Goldschmidt's death, some of the minor elements have become of the utmost industrial importance. Goldschmidt showed where to find them and laid the foundation of their geochemical and crystal-chemical behavior.

The peaceful lives of Goldschmidt, father and son, were fundamentally changed and their work interrupted in 1933. The "thousand years" of the Third Reich had begun. Monsieur François Poncet, French Ambassador in Berlin, summed it up "C'est la victoire des Boches sur les Allemands." Göttingen and the other German centers of learning were systematically destroyed by the Nazis. Many eminent scientists deeply regretted this—but they did not protest, or make a firm stand against the measures taken by the Nazis against science and the arts. Some of V.M.'s students went to Berlin in the hope of convincing the Ministry of Education that V.M. must remain in Göttingen. Goldschmidt and his father, who had not previously belonged to any faith, ostentatiously joined the small Jewish community in Göttingen. V.M. was determined, in the interests of his students, to continue his work at the University as long as he could, knowing that soon he too would be dismissed and forced to leave the country. He became more lonely and withdrawn than before, constantly careful not to "compromise" or endanger his non-Jewish friends and colleagues. His sense of humor became more grim than ever. His father was once perturbed at being greeted by someone with "Heil Hitler." Goldschmidt retaliated by remarking that surely no atheist could be offended if greeted by "Grüss Gott".

He continued to work on his extensive research program; early each morning and again until late each night he sat at his ancient double-keyboard typewriter, writing scores of letters to colleagues and friends abroad, recommending young scientists who had lost their positions for racial reasons. Many young scientists owe to V.M. not only their careers in countries outside Germany, but even their lives.

In 1935, after a new wave of anti-Semitism, Goldschmidt resigned his chair and returned to Norway. The Norwegian citizenship which he had to resign when he went to Göttingen was immediately granted and a chair at Oslo University offered to him. The Goldschmidts arrived back in Norway almost penniless; although emigrants and refugees from Germany were allowed to take their personal belongings with them, the money allowed was only ten marks per person. Much later part of Goldschmidt's money was transferred to Oslo as the result of a very courageous and outspoken letter written by F. K. Drescher-Kaden, V.M.'s successor in Göttingen, to the president of the German Reichsbank, Hjalmar Schacht. The house in Wagnerstrasse and all his other possessions were lost without compensation from Germany.

He rented the top floor of a small house in Holmenkollen, and divided all his energies between his scientific work and helping refugees from Germany and the countries invaded by the Germans before the war. He wrote the ninth and final publication of the "Verteilungsgesetze," a book of 150 pages covering the abundance and distribution of the individual elements and atomic species, and geochemical and cosmochemical data; in this attempt to estimate the mineral mass ratios of the chemical elements he also included isotopes, thus laying the foundation stone of isotope geology. He resumed his work for the Norwegian Raw Materials Laboratory, assisted by his devoted collaborator Aslak Kvalheim (who later became his successor in this governmental laboratory), and he continued his geochemical research. As a side line, and a money-making hobby, he resumed the industrial work he had done after World War I, when he did so much to develop the utilization of Norwegian raw materials. On the west coast of Norway there are large deposits of olivine; Goldschmidt discovered that it has refractory properties, and he himself developed the methods successfully used in industrial furnaces and ceramic kilns of transforming olivine rock into industrial refractories. In addition he made use of olivine sand and crushed dunite rocks instead of quartz sand for making molds for foundries. The olivine molds not only produce excellent castings of steel and high-melting ferro-alloys, but also reduce, and may even eliminate, the danger of silicosis in foundries.

In the tranquility of his new home Goldschmidt was at peace again, although he was distressed by tension and oppression in Germany and anxious about many of his friends still living there. His correspondence was greater than ever, and the file marked "N.A." (non-Aryan) grew daily. A personal tragedy for him was the sudden death of his father, and he became more lonely and withdrawn than before. Future and worse developments in the political theatre, however, soon made him realize that death had spared his father from participation in the coming cataclysm.

I went to stay with him in Oslo shortly after his father's death. He had aged, his health had deteriorated, and he was embittered and tired. But he went on with his scientific and his relief work with almost inexhaustible energy. He spent more than he could afford on helping other people and managed to bring an aged aunt and a niece—still a child—from Germany to Oslo, and the niece from there to the U.S.A. He still enjoyed his food and an occasional drink and he maintained his old-fashioned courtesy. His humor had become more whimsical, more grim, and sometimes even caustic. I remember one day when I asked him to come with me to take some flowers to the crematorium as a tribute to his parents. We stood reverently in front of the urns, all made of beautiful green Norwegian olivine, two with the ashes of his parents and a third, empty and destined to hold his own, and finally V.M. remarked dryly: "Ja, ja, the whole family in magnesium orthosilicate."

His pessimism in those pre-war days was sometimes almost unbearable. He knew the omens and foresaw the coming pandemonium from which there was no escape, and yet he worked and made plans for further research. The spectrographic unit was in full swing, and plans were ready for a new mass spectrometer with which to study the abundance and distribution of isotopes. And then war broke out, bringing the darkest days of Goldschmidt's life. He had always been a man of strong likes and dislikes and could not always see eye-to-eye with his colleagues. During the war, and especially when Norway was overrun by the Germans, he forgot all his animosities in a personal attempt to resist the waves of evil which swept over Europe. He kept in touch with those friends in Germany who still dared to write to him and, in order not to compromise them during censorship, signed his letters illegibly. His main correspondence was with English friends; even during the Nazi occupation many messages reached the Allies through Goldschmidt's help.

By nature timid and anxious, he grew in stature during the war years, but his health suffered. Finally he was arrested by the S.S., his property was confiscated and he was sent to one of the concentration camps which the new masters had installed. These camps were full of the Norwegian intelligentsia—university teachers, lawyers, writers, etc.—regarded as dangerous by the regime. It is true, and it should never be forgotten, that nearly everyone in Norway was engaged in the resistance. Goldschmidt's case, however, was a special one: in addition to being one of the most prominent Norwegians, he was also a Jew, and therefore earmarked for extermination in the gas chamber. In November, 1942, he was listed for deportation to Poland, but at the last moment, probably through the clever intervention of the Norwegian police, and owing to his poor health, he was temporarily released. Then, with the help of the Norwegian resistance he was smuggled across the Swedish frontier in a load of hay which some German soldiers prodded with a fork.

Goldschmidt did not stay long in Sweden. He was eager to offer his services to the Allies, and in the spring of 1943 he was brought to England. It was in this country, and especially in Scotland, that, although seriously ill, he felt at peace again. Under the auspices of the Agricultural Research Council he first went to Craigiebuckler, near Aberdeen, to work at the Macaulay Institute for Soil Research. He was warmly received by its director, Dr (now Sir) William Ogg and his wife, and for the first time in many years he knew what it meant to live in a free country. He took a great interest in soil research and, when Ogg became director of Rothamsted Experimental Station, he moved with him to Harpenden. He was liked by everybody and soon affectionately called "Goldie"; he took the greatest interest in the Institute's work on trace element distribution, and used to remark that it was in England, and through his contacts with Dr Ogg, Dr Alex Muir, and others that he began "to understand what geochemistry really is"—put with great modesty, this was certainly a great appreciation of the excellent work of British soil chemists.

Goldschmidt always hated the writing of papers and books, and he used to tell his pupils in Göttingen to write their papers as concisely as a Scotsman would if they were to be sent by telegram. It was with difficulty that Dr Ogg and his colleagues eventually persuaded V.M. to write his last *magnum opus,* and gave him every facility for his work. But the task was too great and his health already too seriously undermined. Seven hundred folios were written, but he could not finish the rest. The ultimate book *Geochemistry* was completed after years of hard work by Alex Muir with the collaboration of A. Kvalheim and published posthumously by O.U.P. in 1954.

Many honors came to Goldschmidt—he received an honorary degree at Aberdeen University, and also the highest award of the Geological Society, the Wollaston Medal; but nothing pleased him more than his election, as one of its fifty foreign members, to the Royal Society, London. Perhaps, had he lived longer, he would have received a Nobel Prize, which he so richly deserved. His deepest satisfaction, however, was the kindness he received, and the fact of his freedom—in Göttingen, when one Nazi riot followed another, he and his father carried hydrocyanic acid in a capsule for emergency use as a final evasion of Nazi cruelty. In Norway, too, during the occupation, he carried poison in his pocket. On one occasion a university colleague of his in Oslo asked Goldschmidt for a capsule. "This poison," answered V.M., "is for professors of chemistry only. You, as professor of mechanics will have to use the rope." This was the typical grim humor of Goldschmidt. In England he did not need the poison any longer, and in a gay ceremony at Rothamsted it was solemnly buried deep in the garden.

I saw Goldschmidt again in January, 1946, after a long interval, and found him greatly changed in appearance. From then on I went to Harpenden once or twice every week to spend the day with him. His agonizing experiences in Norway and his recent illnesses had made him lose weight and he looked more like a pathetic survivor of a Nazi concentration camp. In spirit, however, he was indestructible; he was still easily hurt if somebody failed to give credit to his work and he suffered, often with justification, from a sense of persecution. His English, although grammatically correct and even fluent, was known as "Goldschmidt English" because of his quaint pronunciation. As usual he was more generous than his means really allowed and the pockets of his suits, which always became baggy, bulged with dozens of small pieces of paper: notes of atomic constants, old bills, bus tickets, and the addresses of people to whom he wished to write, or whom he wished to help in their academic career.

In one fundamental way he had changed: the bitterness had gone—he no longer hated those who, in so grim a way, had twice interrupted his work, undermined his health, and shortened his life. One episode influenced V.M. deeply and occupied his mind until the end of his life: it happened early in November, 1942, in the County Hospital in Tönsberg, Norway, which was then the internment camp for Norwegian Jews. After a day of humiliation and torment by his Nazi jailers, V.M. talked to two other prisoners, whose names deserve to be recorded: Moses Katz, an orthodox Jew and a hosiery peddler, and Lesser Rosenblum, socialist, atheist, and manufacturer of umbrella handles. V.M. suggested that they should remember the names of their tormentors, so that any survivors might exact retribution. The reply of the pious Moses Katz was a surprise to V.M.: "Revenge is not for us; that must be left to the Almighty." With the arrogance of a scientist confident of his superior knowledge, V.M. asked what prayers would be permissible to God from men in their position. Katz replied without hesitating a moment: "You may pray that the hearts of your enemies may be enlightened." Goldschmidt, still not admitting defeat, turned to the atheist Rosenblum and asked for his view. His reproof was equally unexpected: "We must break the evil circle of retribution, or there can never be an end to evil."

Goldschmidt became very humble after this experience. He had escaped, but his two friends from Tönsberg were facing death in Poland's gas chambers. He regarded their sayings as lucid and practical improvements on the Old Testament. Through them he learned not to forget, but to forgive.

The prolonged strain he had undergone, his escape, and the frequent adjustments to new countries and languages and people had completely undermined V.M.'s health, and for weeks he had to stay in bed. On one occasion he was staying with the Oggs. Dr Ogg, on his way to bed very late, heard groans coming from V.M.'s bedroom. He had had a heart attack and was convinced that he was dying. Between groans he kept saying "This is the end. I have done my best for Norway and Britain." A doctor was called at once and Goldschmidt was given oxygen; but his condition was critical and the doctor, scarcely expecting him to live until the morning, gave Dr Ogg the name and telephone number of an undertaker. V.M. appeared to be unconscious but evidently heard these remarks. He had enormous will power and was not yet prepared to be defeated by illness. When he was being carried out to the ambulance in the morning he was joking about the undertaker.

His mind worked constantly; many fascinating theories occupied him and were developed in talks with visiting friends. No record of these is available as Goldschmidt never committed to paper, or published, ideas which he could not yet prove. He strongly disliked the premature publication of theories: "Make two thousand experiments, and then you have your theory and can publish both," he used to say.

However, he did write two papers which, for different reasons, he was unwilling to publish. There exists a handwritten manuscript, "Geochemical Aspects of the Origin of Complex Organic Molecules on the Earth as Precursors to Organic Life." It was published after his death in a series of popular scientific books but has remained practically unknown to scientists, and Goldschmidt himself would never have agreed to its publication in its unfinished form. Some of the ideas expressed in this draft may one day reappear and their significance be recognized.

The second paper—actually more a note—was written in cooperation with G. Nagelschmidt and was never published because Goldschmidt felt it was, perhaps, undignified to end his fundamental scientific work with a note on *album Graecum* (dog feces), a prosaic and unattractive product, however interesting in its chemistry, in which insoluble phosphates are transformed into white and soluble ones. It may be recalled that before World War I it was used in the manufacture of fine, high-grade leather. The idea of this note must have come to V.M. during the war, when he grew vegetables in a small suburban garden outside Oslo where many people kept dogs. *Album Graecum* is an ideal phosphate fertilizer for a poor soil; but if it would be undignified as a scientific paper V.M. thought it would be even more undignified for a middle-aged professor to collect *album Graecum* from suburban pavements for his garden. He was in any case a very reluctant gardener, and had a widely representative collection of weeds in his allotment.

For several months in Harpenden, when he was too weak to leave his bed, he must have felt that his life was slowly drawing toward its close. He did not speak of the disappointments, the sorrows, the pains, and the dangers he had experienced, but of bygone and happy days; of Göttingen and his friends and pupils who resumed contact with him after the war. He was happy that his old Institute had two of his friends as his successors, first F. K. Drescher-Kaden and after him C. W. Correns; and he was happy that his work was carried on by the younger generation which had been so strongly influenced by him. In his weakness V.M., who had never spoken German since 1939, sometimes lapsed unconsciously into his mother tongue. It was a moving experience to visit Goldschmidt in those days—the lonely man with some enemies, but with many devoted friends. These he remembered in gratitude, the others he forgot. "Should you see Dr Lonsdale or Professor Tilley, and if you write to my old friend Eskola, please remember me to them," he would say, wanting them all to know that he was still alive. He could no longer go to see the Oggs, but they came and looked after him and he kept his friendship and gratitude for them until he died.

However, his time had not yet come. He recovered sufficiently to prepare for his return to Oslo. Once he felt better, his unfailing will power took possession of him, and he made plans to resume his scientific work on a large scale. At the end of June, 1946, he left England and arrived safely in Oslo. "Father's Return" was celebrated enthusiastically at the Raw Material Research Laboratory, and he was delighted to see among other friends W. Zachariasen of Chicago University, one of the pupils of whom he was most proud. At his flat much of his furniture had been recovered with the help of the government, and there were letters from Göttingen, offering him his old chair and from China, inviting him to organize raw materials research in that country. Soon, however, he had to undergo examination and treatment in several hospitals. His reports were optimistic, heart, kidneys, and lungs seemed to be satisfactory, and he hoped to have several years ahead in which he could work, provided he "followed the recognized principles of Moses Katz." Miss Brendigen had again joined his household, and had provided him with what he regarded as a delicious specialty, fresh whale meat! In October for the first time he mentioned a black spot on his leg; he received X-ray treatment, but the growth proved to be malignant and required surgery. The carcinoma could not be removed completely, and again Goldschmidt had to go into the hospital. Still he continued working on his book, directing scientific and industrial research and writing letters to his friends. In March, 1947, he entered the surgical ward for the sixth operation. On March 19 I had a few scribbled lines that the operation had been successful and that he would be allowed to go home on the following morning. He arrived home on the twentieth, complained of a sudden intense pain in his head, and died almost immediately.

In one of his last letters to me he wrote:

> The wisdom of the Moses Katz principles is undeniable. . . . And I am fully convinced that it is my duty towards science and decency to stand firm in continuing my work as long as health permits, thus giving an example to at least some of my junior colleagues. Often I think that (to maintain these principles) to be even more important than my contributions to scientific and industrial research and my scientific teaching. To set a new standard of morality is a matter of great urgency in these times . . .

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# Victor Moritz Goldschmidt (1888–1947)*

C. E. TILLEY

VICTOR MORITZ GOLDSCHMIDT was born in Zürich on 27 January 1888, the only child of Heinrich Jacob Goldschmidt and Amelie Goldschmidt (*née* Koehne). His earliest schooling he received at Amsterdam and Heidelberg, and later at Oslo, where his father became professor of chemistry in the University in 1900.

In Oslo he attended the Vestheim school, matriculating in 1905, and in the same year he and his parents became Norwegian citizens. At the University which he entered the following session he studied mineralogy and geology under W. C. Brøgger, and inorganic and physical chemistry under H. Goldschmidt and Th. Hiortdahl. There, through the influence and inspiring personality of Brøgger, he was soon to be drawn into research in the fields of mineralogy and geology, and to embark upon the first of the remarkable series of researches which have illuminated the study of rock metamorphism.

In the course of these formative years he studied for a short period during the winter of 1908–1909 under F. Becke in Vienna, and he spent the winter session of 1911–1912 with von Groth at Münich. He gained his doctorate at Oslo in 1911, was made docent in 1912 and appointed in 1914, at the early age of 26, Professor and Director of the Mineralogical Institute in the University. From this time till 1942, apart from a period of six years at Göttingen (1929–1935), his interests and activities were to be associated with his chair at Oslo.

Goldschmidt's achievements in mineralogy and petrology, and in the study of the regional geology of Norway, rank in importance with those of his illustrious teacher and predecessor. They were sustained and succeeded by researches of brilliant distinction which not only laid the foundation of a new science of inorganic crystal chemistry but gave to geochemistry its modern orientation and much of the impulse to its present phenomenal development. Pre-eminent in achievement, of great range and depth, these collected investigations remain to give him rank as one of the most outstanding men of science of his day and generation.

At Oslo and Göttingen he gathered around him an able and enthusiastic group of pupils drawn from many countries, attracted and inspired by his genius and example. Many of them, now come to advancement in professorships or high posts in industry in Europe and America, are building on the foundations he laid and have been responsible for some of the most recent developments in the wide fields he made his own.

Goldschmidt's first published paper appeared in his first year at the University. It dealt with the pyroluminescence of quartz, a subject which had taken his youthful interest as early as 1904. This earliest effort in research gave clear indication of the resourcefulness and thoroughness with which later investigations were to be conducted.

He contributed a paper on the germanium mineral argyrodite, and indicated how the measurement of radioactivity of minerals could be used as an aid in the identification of some of the rarer species, such as orangite, samarskite, euxenite and polycrase. But the main work of these early years was to lead to his doctorate thesis on contact metamorphism in the Oslo area.

In the spring of 1907 he had begun a study of the mineral deposit of Årvollsdalen near Oslo with its rich assemblage developed in the calc silicate xenoliths in the surrounding nordmarkite. Eventually at the suggestion of Brøgger these studies were enlarged to embrace the aureoles of metamorphism around the major igneous intrusions of the Oslo area. The Permian plutonic igneous masses of the region had long been celebrated by the work of Brøgger, and Goldschmidt was now to engage on a close investigation of the thermal metamorphism induced at their contacts with the varied group of Palaeozoic sediments. As a result, there appeared in 1911 in a memoir of more than 400 pages a masterly contribution to rock metamorphism which has since become a classic.

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* From: *Obituary Notices of Fellows of The Royal Society,* Vol. VI, 1948–1949, pp. 51–66. Reproduced by kind permission of The Royal Society.

A study marking a major advance in the correlation of the chemical and mineralogical composition of thermally reconstituted rocks, it contained the first successful essay towards a systematic classification of rock mineral assemblages in the light of phase rule theory.

Goldschmidt's mineralogical phase rule was developed by the consideration of solid phases in contact with their saturated solutions, a method having the advantage that it probably provides a real picture of the processes in operation in contact metamorphism. In this way he set up for the shale-limestone group of sediments an orderly group of ten equilibrium assemblages (classes) the validity of which has been abundantly demonstrated in later work.

Goldschmidt was among the first in Europe to recognize the importance of metamorphism in connexion with skarn development associated with certain classes of ore deposits. Thus, in this same study he recognized in the Oslo region a pneumatolytic metamorphism associated with the ores of the contact zone, responsible for the production of the associated skarns rich in hedenbergite and andradite. He thus joined forces with Kemp and Lindgren in America in recognizing the importance of magmatic transfer of common elements of ore deposits, iron, silicon, sulphur and copper, especially in limestone environments. Later he was to provide in the Langesundsfjord area of the province, clear evidence of sodium metasomatism associated with nepheline syenite pegmatites at their contacts with Downtonian sandstone.

His physico-chemical approach to problems of rock metamorphism led further to an interesting attack on the important problem of geologic thermometry. Assuming the validity of the Nernst heat theorem he endeavoured to calculate the *pt* curve of the univariant equilibrium $CaCO_3 + SiO_2 \rightleftarrows CaSiO_3 + CO_2$. The data for this evaluation were uncertain, as he recognized, and he drew attention to the value of a precise experimental investigation of the system in providing a reliable temperature recorder in metamorphism. The system still awaits experimental study.

The winter of 1911–12 spent at Münich with Groth provided at this time two papers, one an investigation on the change of interfacial angles of non-cubic crystals at low temperatures, research which in conjunction with the work of F. E. Wright on the same materials at high temperatures, has provided a remarkably complete temperature history of two such important substances as quartz and calcite; the other an account of his ingenious conversion of a single circle goniometer to a two circle type which has all the advantages of the more costly three circle instrument in permitting, in a single setting, ready measurement and comparison of interfacial and interzonal angles of isomorphous series of substances.

With the completion of his studies on the contact metamorphism of the central part of the Oslo region Goldschmidt turned his attention to problems of regional metamorphism. As a first stage in this approach he had intended a comprehensive investigation of the metamorphism of the Langesund region where Brøgger's studies had demonstrated that through combined action of heat and the local impress of stress, rocks had developed with the habit of crystalline schists. This part of his programme though apparently brought near to completion was never published.

For the main field of his labours in regional metamorphism he chose the great Caledonian geosyncline of southern Norway where a sedimentary succession can be traced through all stages of alteration into crystalline schists, their metamorphism being in part associated with a contemporaneous suite of eruptives. The geological work of the pioneers, Brøgger, Bjørlykke, Reusch and Rekstad had provided the basis from which an intensive geological-petrographical study might now be elaborated. The region over which his projected studies were to range comprised a belt of country stretching for a length of 500 km with an average breadth of 150 km from Stavanger in the southwest to Meraker in the Trondhjem district to the northeast. It included the great belt of Caledonian orogeny and igneous action associated with a zone of overthrusting towards the southeast along the Caledonian front. These researches are set down in five monographs under the general title "Geologisch-petrographischen Studien im Hochgebirge des südlichen Norwegens."

In the Finse region, an area of great significance in the elucidation of the tectonics of south central Norway he contrasted the hornfels-like alteration of the Cambrian conglomerates preserved and protected from stress in hollows on the sub-Cambrian land surface with the gneissic deformation of the old granite occurring as disrupted blocks in the schistose alum phyllites of Sandaadalen, above this horizon, and in a later contribution he presented a general picture of the metamorphism of the Caledonian geosyncline. In the Trondhjem district he was able to map zones of progressive metamorphism marked by index minerals of argillaceous sediments, chlorite, biotite, and garnet, unaware, it is clear, of the much earlier zonal work of Barrow in the southeast Highlands of Scotland. The progressive metamorphism of the calc silicate rocks of this same region was exhaustively studied and it is of interest to note that his treatment contains a development of the concept of metamorphic facies proposed by Eskola in 1914 and further elaborated by that investigator in 1920.

In his monograph on the igneous rocks of the Caledonian mountain region his attention was devoted especially to three rock suites he recognized—the "green lavas" and associated intrusives, the Bergen-Jotun series of charnockite-anorthosite type and the opdalite-trondhjemite suite. Their eruptive provinces he showed were partly separated in space and partly overlapped and he recognized a possible genetic relationship between the green rocks and those of the trondhjemite suite. It was a detailed study of the petrography and geological environment of these suites (*Stämme*) which brought him to support the conception of petrographical provinces and to the conviction that differences among igneous rock series were dependent in the first place on geological environment rather than on contrast of original chemistry. In these deductions he was elaborating a thesis earlier developed by Harker.

His trondhjemite suite he recognized as characteristic of the active stages of mountain growth from a geosyncline, and owing its special mineralogical character to the special environment of intrusion among the wet sediments of the geosyncline. On the other hand though its Caledonian age could not be demonstrated, the charnockite-anorthosite suite of the Jotunheim he considered the product of crystallization of a dry magma intruded in an anhydrous environment of older rocks.

An important contribution to the tectonics of the Eastern Jotunheim was made in his study of the *Hoifjeldskvarts* conglomerates. The Bergen-Jotun igneous suite already referred to, has suffered much from tectonic disturbance and in its eastern outcrops the gabbros of the suite lie as sheets over the Palaeozoic sediments and are in places intensely mylonitized on their lower surfaces. Goldschmidt in a study of the region between Gudbrandsdal and Valdres found that the boulders of the conglomerate which overlie Ordovician phyllites consist of a gabbro identical with that seen in the gabbro masses overlying the conglomerate. He was led tentatively to the conclusion that these conglomerates of Caledonian age were formed in front of a thrust gabbro mass impelled from behind and moving at the surface or under cover of water only. The gabbro masses he pictured as occupying a similar tectonic position as many *Klippen* of the Alps and related themselves to the *Hoifjeldskvarts* as the Alpine *Klippen* to the *Flysch,* the gabbro conglomerates being paralleled with the exotic conglomerates. But the Alpine analogy was here exceeded for he recognized the thrust masses of the Eastern Jotunheim as travelling over their own conglomerates. In a neighbouring district he recorded a quartz conglomerate developed in similar relationship to a thrust mass of granite.

Active field work in this geological series of researches was brought to a close in 1917 but the final monograph did not appear till 1920. In his study of the injection metamorphism of the Stavanger region he portrayed convincingly the nature of the metasomatic metamorphism associated with intrusions of the trondhjemitic suite and he set up a new standard of achievement in the investigation of injection complexes by this exhaustive and quantitative study which has served as a model for all later work. The results he demonstrated on the ground, at a memorable international gathering of geologists which he himself had arranged, in the summer of 1922. The realities of metasomatism worked out in this field and in the aureoles of the Oslo igneous massifs led him eventually to present a study on metasomatic processes in silicate rocks, distinguished especially for the recognition and formulation, in the light of the mass action law, of the principle of minimum concentration for effective metasomatism.

Goldschmidt's researches in geochemistry were initiated during the First World War when the deficiency of raw materials led him to extended investigations on the mineral resources of Norway. The organization of this research was entrusted to him by the Norwegian government in 1917 and he became Chairman of the Commission for Raw Materials and Director of the Raw Materials Laboratory. The origins of modern geochemistry may be said to date from this period. After the close of the war he set himself to continue research along more general lines than was possible during the years before—in a study of the general scientific problems intimately connected with the utilization of mineral raw materials. As he himself has written of his programme at that time—"Among the problems proposed there was one of outstanding importance, i.e. to find the general laws and principles which underlie the frequency and distribution of the various chemical elements in nature—the basic problem of geochemistry. I proposed to attack the problem from the viewpoint of atomic physics and atomic chemistry and to find out the relationships between the geochemical distribution of the various elements and the measurable properties of their atoms and ions."

With a small team of co-workers he applied himself with great energy to these studies. To this end both old and new methods of chemical and physical analysis were brought to bear on the investigation of rocks and minerals. X-ray analysis and quantitative spectrographic methods provided new lines of attack. Chemical analysis by X-ray spectra had been first applied to mineral analysis by Hadding working in Siegbahn's laboratory in 1922. Goldschmidt was quick to adopt this new development. His memoir with Thomassen on the distribution of the rare earth metals in minerals, published two years later, demonstrating the greater relative abundance of the elements of even atomic number in this series, in harmony with the rule of Harkins and Oddo, was a singularly successful example of its use. But one of the first problems he attacked at this time was the partition of chemical elements between systems of co-existing liquid phases—molten iron, liquid iron sulphide and fused silicate, a matter of obvious importance in metallurgy, petrology, meteorite study and indeed in planetary chemistry. From experience of metallurgical practice, an intimate knowledge of the composition of meteorites and a mass of geochemical analytical data he was led to subdivide the commoner elements into the groups siderophile, chalcophile and lithophile characteristic respectively of the metal, sulphide and silicate melt. These studies brought a special contribution to the problem of the chemistry of the earth's deep interior for with Tammann he conceived the earth ball as a three phase system, recognizing an intermediate sulphide-oxide shell between the metal core and a silicate outer shell. He now added a further "atmophile" group of elements to his classification, those concentrated in the gas phase of the primordial atmosphere. The principles of partition of the elements among immiscible phases he was later to elucidate more fully and finally to add a fifth "biophile" group of elements to his geochemical classification, those concentrated by living organisms in the later stages of terrestrial evolution.

So were initiated the classical series *Geochemische Verteilungsgesetze der Elemente* in which he was ultimately to lay the foundation of inorganic crystal chemistry though he recognized it as simply one aspect of the general geochemical problem he had set himself many years before.

Looking back in 1926 he could write "The experimental work in the field of crystal chemistry which in recent years the Mineralogical Institute of the University has undertaken had the objective to throw light on the geochemical distribution and technical properties of practically important materials. During the carrying out of these researches . . . there appeared a series of general crystallochemical relationships which made possible a notable deepening of the principles and data of crystal chemistry."

In the first place it may be imagined that he thought of the X-ray methods as just one of the auxiliary methods for the examination of minerals to be used when other methods failed. He started this work at the beginning of 1923 and from then on until 1929 when he moved to Göttingen, he and his small group of research workers several of whom like T. Barth, Zachariasen and Oftedal were subsequently to become noted X-ray workers, carried out what is still the most remarkable planned series of X-ray studies that has ever been undertaken. Although the work set out in Nos IV to VIII of the "Verteilungsgesetze" seems to show an absolutely straightforward progress it is clear from internal evidence that Goldschmidt enlarged his views as he went along while maintaining the unity and purpose of the project. In the course of the work nearly 200 separate chemical compounds were prepared and analysed by X-rays and the results published in 45 different papers. At the time when Goldschmidt started this work crystal chemistry as a scientific discipline did not exist. As he wrote in his preface to "Verteilungsgesetze" No. VII—"For the mineralogist and for the practical chemist crystallography was a purely descriptive auxiliary science which made possible the recognition and distinction of crystalline materials whether they were minerals or technical products."

He was progressively to give it nearly all its leading ideas. It is characteristic of his geochemical interest that the first series of compounds examined were those of the uranium group of elements—uranium oxide, thorianite, cleveite and bröggerite.* He saw that the similarity between these from the X-ray point of view was much more important than the difference revealed by chemical composition. In the same paper he discusses the close relations between yttrofluorite ($YF_3$) and fluorite ($CaF_2$) and thus was immediately plunged into all the difficulties involved with pseudoisomorphism and defect structures. The really effective beginning of the crystal chemical work came, however, with his masterly study of the sesquioxides, first of the rare metals and then of the other trivalent elements. His interest in these was clearly geochemical in the first place, but the magnificent series of rare earth sesquioxides enabled him to show the existence of the three crystal types (*a*), (*b*) and (*c*) in each of which isomorphism went with a steady change in lattice dimensions, the celebrated lanthanide contraction, the significance of which he was the first to point out. It was obvious to him from these extended series in the light of his deep understanding both of geochemical distribution and of the periodic table that both the contraction and the morphotropy of the sesquioxides depended on a continuous change with atomic number in the size of the rare earth atoms. Now atomic size had been discussed even before the first analyses of crystal structure but there had been a very natural confusion between atomic volumes derived from the densities of the elements expressed in the Lother Meyer curve and interatomic distances from binary compounds. This difficulty was not effectively cleared up until the work of Wasastjerna in 1932 [*sic;* 1923(?), ed.] and Goldschmidt was one of the first to make use of Wasastjerna's new picture of large anions and small cations to which he furnished the most extensive series of examples. It was in meditating on the transition from one crystal type to another, brought about by comparatively slight changes in the radii of the cations, that he saw that the laws of co-ordination already postulated years ago by Werner to account for complex salts also held the key to the structure of simple ionic crystals. Very small cations fit between two anions, larger ones between three, four, six and eight. The characteristic mean size for a cation to fit in a definite co-ordination sphere of anions was, he saw, fixed by the simple geometry of the radius ratio of the two ions. Thus all simple binary compounds AX had 3:3 co-ordination if the radius ratio was less than 0.22, 4:4 if it lay between this and 0.41, 6:6 up to 0.73 and 8:8 beyond this. The series did not end there; if, as sometimes is the case, the cation was actually larger than the anion it descended in the same order giving rise to what Goldschmidt was the first to call anti-isomorphous substances which might have the same crystal structure by an interchange of positive and negative ions but which could never, unlike isomorphous substances, give rise to mixed crystals.

Goldschmidt, however, had no sooner found this law than he realized that it held many exceptions and indeed he only made it the starting point of his series of fundamental laws of crystal chemistry. The law broke down under the circumstances which he clearly distinguished—if the anion was large, such as sulphur or iodine, or even more where the anion was a complex such as OH, the anion was deformed by the strong polarizing field of the cation leading to structures which approximated far more to those of the molecules of organic chemistry. This was particularly true where, as in such sheet-like structures as molybdenite, all the cations were on one side of the anions. Goldschmidt was the first to distinguish between the relative importance of the polarizability of the anions which was that already established by Fajans for their optical properties, and the polarizing power of the cation which was directly proportional to its charge and inversely to its radius. In this way he was able to arrive at the general law that "the structure of a crystal is determined through the numerical proportions, the ratio of sizes and the polarizability of its units."

The other region where even this rule breaks down is in those structures where the binding is very markedly non-ionic, particularly in the compounds between the transition elements and those of the IVth, Vth and VIth B groups of the periodic system. Goldschmidt showed that the laws of interatomic distances in such compounds as the compounds of the diamond, wurtzite or nickel arsenide structures obeyed quite different rules from those of ionic compounds. The interatomic distances in fact remained sensibly constant as long as did the ratio of electrons to atoms, whatever the valency of the individual atoms. He was thus led to postulate two incommensurable types of structures, one being the ionic and the other semi-me-

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* In his much later published paper "Om super-uraner grunnstoffen med storre Kjerneladning enn 92" he returned to the Uranides and showed how the new artificial elements fitted into the scheme he had elaborated.

tallic or adamantine, though no simple name has yet won general acceptance.

The whole of Goldschmidt's work was summarized in a masterly way in the two great penultimate papers of the "Verteilungsgesetze" VII and VIII. There has rarely been in the history of science an example of an enunciation of fundamental laws combined with a wealth of well-ordered and precise data determined at the same time by the same person. With the publication in 1926 of these two numbers, modern crystal chemistry received its first and definitive form. It contains not only a detailed description of the radii of almost every ion to be found in the periodic table, but of the description and explanation of all the structures for the types $AX$, $AX_2$, $A_2X_3$, $ABX_3$, $ABX_4$ and $A_2BX_4$ which include between them most of the simpler inorganic compounds. It was accompanied by tables and diagrams of atomic radii that became from the start the basic data for all subsequent crystal chemical work. In these two papers Goldschmidt discussed not only the general laws already referred to including those of polymorphy, isomorphism and morphotropy, but showed how they followed from the very nature of the coulomb attractions between the ions, thus doing on an extended scale what Born had achieved with the refinements of mathematical physics for the simpler structures.

In this work Goldschmidt had succeeded in solving the basic geochemical problem that he had put himself at the start of the investigation, namely—what are the characteristics of atoms that determine their distribution in the crust of the earth? He showed that for the most part these were ionic size, charge and polarizability. This work, combined with the knowledge of silicate structures derived from the Bragg school, explained with the utmost elegance and simplicity the puzzling rules of ionic substitution in minerals. The older mineral chemists had used the analogies of organic chemistry in putting forward formulae for the complex minerals such as the micas and feldspars. Goldschmidt showed that they were on the wrong track and in fact a much simpler explanation was that of the piling of spheres in different sizes. The possibility of substituting any one atom by another even of different charge was possible so long as ionic sizes did not diverge too much.

He extended the theory beyond this to explain the physical properties of crystals. He showed, for example, that the hardness of crystal was determined by the charge and distance between the closest ions and established the two parallel series, so called model structures of the relatively soft fluorides with single charges and the hard oxides with double charges, and in which each anion in the first series was matched by another of the same radius and double the charge in the second. Thus the idea of model structures was to prove extremely valuable in the further elucidation of the complex minerals.

Goldschmidt did not stop there, however, he went on in one last but illuminating extensive study of the metallic state, thus rounding off the whole picture of inorganic chemistry. Here, guided by this idea of the importance of co-ordination he was able to establish sets of atomic radii corresponding not now to different atomic charge but to different co-ordination number and thus provide the most beautiful illustration of the regularities of the periodic system of the elements, free from anomalies produced by accidents of different crystal structures. Thus bismuth, which normally crystallizes in an irregular 6 co-ordination can be made to alloy in 12 co-ordination with a reduction in effective volume of 8%. Having thus put light and order into a field of study which hardly existed before his time, Goldschmidt after 1928 returned to his main preoccupation with geochemical problems. His work, however, was at once seized on by crystallographers and crystal chemists and made the basis for all subsequent studies. Neither in general principle, nor in any important particular, has it been shaken to this day. The first great work of Pauling was in extending the conceptions of Goldschmidt to cover the more complex silicates whose structures had been determined by the Bragg school. Naturally this involved refinement of the purely empirical atomic and ionic radii determined by Goldschmidt but these are still the most convenient for practical use. His work on the semi-metallic and metallic structures has also stood the test of time and many of his minor interests such as those of non-Daltonian ratios in minerals have proved most fertile. Goldschmidt's work, however, in this field is much more than the establishment of the fundamental rules of crystal chemistry and the determination of its constants for nearly all the elements. He built the foundation on which modern inorganic chemistry rests and we may soon hope to see his ideas taken as the basis for the elementary as much as for the advanced teaching of inorganic chemistry.

In the third main period of his scientific activities

Goldschmidt worked in Göttingen. On the retirement of Mügge in 1928 he was invited to fill the Göttingen chair and he became director of a large new mineralogical institute which he organized on the model of his Oslo laboratory.

He moved there in 1929 and began a long series of geochemical investigations on the rarer elements. For the most part his methods of analysis were now founded on carbon arc spectrography. With his colleagues Mannkopff and Peters he developed the cathode layer technique, capable of detecting most elements in concentrations down to 0.001% or even less and adapted for the treatment of much smaller quantities than hitherto in spectrographic work. A stream of publications dealing with the geochemistry of selected elements, among them, gallium, germanium, scandium, beryllium, boron, the noble and the rarer alkali metals, was issued during the years 1930–1935 in the Göttingen *Nachrichten.* It is not too much to say that the elaborate series of investigations mainly carried out at this time has revolutionized our knowledge of the distribution of the minor constituents of the earth's crust. They were based on a wide selection both of terrestrial and meteoritic matter and he spared no pains in gathering materials for research from all quarters of the globe. He was ultimately to present a broad synthesis in a general survey tracing the partition of a large number of these rarer elements among the successive products of the geological cycle from the primitive magma to the sediments and the sea. He drew an illuminating picture of the sifting and sorting of the elements in the fractional crystallization of igneous magma and demonstrated the effects of ionic size and charge in regulating the sequence of entry of elements in the host silicate structures of the consolidating igneous rock. He essayed a quantitative balance of substances through a succeeding stage of weathering and sedimentation—in the residual sediments and through solutions to the sea—and employed the function of ionic potential, the quotient of ionic charge and size, introduced into physical chemistry by Cartledge, as a guiding principle in the distribution of the elements at this "aqueous" stage of geochemical evolution.

It was on the basis of the ionic potential that he drew distinction between three major groups of elements in the process of sediment formation, those remaining in true ionic solution, those precipitated by hydrolysis and those forming soluble anionic complexes, groups which can be clearly recognized as common products in distinctive units of the sedimentary record. The principle thus empirically derived, and in his hands successfully exploited, has yet to be grounded with an adequate theoretical foundation, but the effective use he made of his own fundamental discoveries in crystal chemistry in interpreting his data and indeed in predicting geochemical phenomena, is apparent on every hand in these comprehensive researches.

He went on in sequence to the consideration of a further stage of the geochemical evolution of matter in his analysis of the processes of concentration of elements due to the action of living organisms—the province of biogeochemistry. His interest here had been stimulated by his discovery that germanium occurs concentrated in certain coal ashes—such as those of Northumberland and the Donetz basin. He found that a concentration of a great number of minor elements occurred in forest humus and forest litter and traced a circulation of these elements in solution from the subsoil through the plant to ultimate precipitation and enrichment in the topmost layers of forest soils. The phenomena of enrichment thus disclosed have in recent years been successfully adapted in a type of geochemical (spectrographic) prospecting where a systematic search for a concentration of trace elements in vegetation or soil humus may give clue to the site of an underlying and hidden mineral deposit.

Goldschmidt's term at Göttingen came to an end in 1935. In the face of growing Nazi anti-Semitism he resigned his chair and returned to Norway, regaining Norwegian citizenship. A little later (1936) he succeeded to a professorship which became vacant at Oslo on the death of Schetelig. He set up a spectrographic unit as a section of the Norwegian government's economic laboratory and continued research along the lines established at Göttingen. Working with renewed energy he brought out the ninth and final publication in the "Verteilungsgesetze" series. In this work he linked up a mass of geochemical and astrophysical data as well as data from nuclear physics and he attempted an estimate of the universal mass ratios not only between the chemical elements but also of the isotopes, devoting some attention finally to the interrelation of the frequency of the different isotopes in the universe, their stability and the conditions of their formation.

During the period of his association with the government laboratory in Oslo he did much to stimulate interest in, and to develop, the mineral resources of Norway. He was a pioneer in the development of forsterite as a commercial refractory and spent much time on the problem of the utilization of the large Norwegian deposits of olivine on the west coast, particularly those of Sondmøre. Already in 1928 he had made industrial experiments on the use of olivine sand and crushed dunite in place of quartz for making moulds for foundries but these results had remained unpublished. In the succeeding years the industrial use of olivine refractories was largely developed in Germany, utilizing his methods of transforming olivine rock into a mixture of forsterite and magnesium ferrite by burning with magnesia. Such refractories have had successful use in ceramic kilns and for the roofs of copper-refining furnaces among other adaptations. One of his last papers (1945) issued in collaboration traced the effect of olivine on the lungs of rats, a test of olivine dust in problems of silicosis which showed that its substitution for quartz in some foundry processes should be effective in reducing the incidence of that disease.

He worked on the development of titanium pigments, the importance of mica minerals as a source of potassium for plants and suggested the possibility of using biotite to this end. Though his suggestion was not altogether new the resulting experiments he developed are probably the most complete set yet carried out to test the possibilities. Among other developments were his process of making alumina from anorthosite, a rock in which Norway was abundantly supplied.

During the Second World War and after the German occupation of Norway, Goldschmidt suffered severely at the hands of the Nazis. He was twice arrested and finally in October 1942 was sent to a concentration camp, the whole of his property being confiscated. At the end of November of that year he was sentenced to immediate deportation to Poland. At the last moment this order was cancelled and he succeeded just before Christmas in escaping across the frontier to Sweden. He came to Britain in the spring of 1943 and offered his services to the Allies. Here he worked under the auspices of the Agricultural Research Council, spending the first year at the Macaulay Institute for Soil Research, Aberdeen, and later went to Rothamsted Experimental Station where he remained until his return to Oslo in June 1946. His experiences during the war years had led to a serious deterioration in his health and when he returned to Norway he was very weak after long and serious periods of illness. He seemed to be making a good recovery after an operation and his sudden death on 20 March 1947 came as a shock to his friends who saw him regularly.

For some years before his death Goldschmidt had been engaged on a comprehensive treatise on geochemistry, synthesizing his researches of 25 years. The greater part of it was in draft before he left England and more was completed in his last days in Norway. These chapters are now being translated or corrected for the press and it is confidently expected that they will soon be published in this country.

Goldschmidt was a man of amazing energy and fertility of ideas. Not even periods of illness could diminish the ardour of his mind, incessantly directed to the solution of problems he set himself. First and last a scientist, he viewed everything in relation to science and research. A complete list of his publications runs to more than 200 titles, many of them covering monographs of great length. Within his own fields his knowledge was phenomenal and his memory stupendous and he gave the impression that he had most of the existing literature in his mind. Professor Born has related that at Göttingen he once sent an assistant to Goldschmidt to ask about literature on a great number of data. Instead of giving the titles of papers Goldschmidt just dictated numerical tables from memory and a later check proved them essentially correct. He knew by heart not only the properties of atoms and ions, like radii and polarizabilities, but also their intimate occurrence in minerals, and it seemed that if he did not know a fact he had some simple way of deriving it from his radii. He remembered at once where he had buried a paper he wanted, and this was all the more astonishing as he had a system not to tidy up a writing-desk but to start a new one, when the old one was piled high with papers. So gradually nearly every room in his house came to have a writing-desk until there was only a kitchen sink in an unused kitchen left and even this was covered with a board and turned to the prescribed use.

In conversation one might get the impression that in his enthusiasm his ideas were running away with him but such exuberances were never committed to print where he was most careful in weighing his words. Scientific honesty was indeed with him a first principle.

At home in Göttingen he lived with his old father, as if they were two brothers—in fact they came to be known as Old-Brother and Young-Brother. In the University Faculty meetings he was always quiet and polite; he spoke seldom, and if he spoke, he did so slowly, with great deliberation and clarity.

His addresses given to the Gesellschaft der Wissenschaften were brilliant, a wonderful mixture of exact measurements and the keenest combinations of ideas to interpret them. He often said that he was happy in Göttingen because he had in the Gesellschaft a group of men who understood and appreciated his work as indeed they did.

He had a great fund of humour which took at times an extravagant or caustic form brought out in some of the legion of Goldschmidt stories. It is reported that when Hitler first came into power Goldschmidt appeared at a Göttingen meeting with his hair cut more than usually short. His colleagues commenting upon it, he tapped his head and said, "Damit es besser rollen kann"; and after, when he was in England and returning to Norway, he remarked, "I owe two things to Hitler; first, without him, I would be a geheimrat professor with nothing to look forward to but ease and honour. Now I have lost everything and have the chance to be young again," and he added, "Besides it has taught me a lot; you see, in ordinary life there is every inducement for people to behave decently, but under Nazi-ism it is quite the contrary and yet I find a number of people who do behave decently—even among the educated classes." His love of, and patient approach to, animals was great. He had tamed birds and squirrels in his garden and these were all given names which had some funny allusion to people he knew. If, on occasions, in his judgment of men and situations he was apt to exaggerate and react childishly, it is to be remembered that the lapses were those of a generous but sensitive nature, and that he was quick to acknowledge his mistakes and make amends. To those who came to understand this, he was a devoted and loyal friend.

He ruled in his department with benevolent tyranny and his pupils and collaborators adored him. He took a keen interest in their welfare and they became his personal friends. In his recognition of their work he was liberal and was ever ready to place his knowledge at their disposal even though at the time deeply engrossed in other problems.

When he came to Britain his health was already seriously undermined. He deeply appreciated the help extended to him at the Macaulay Institute and at Rothamsted, and while his main preoccupation was the completion of his *Geochemistry* he spent much time with his colleagues, was generous with his advice, and took great interest in their work of trace element distribution.

Honours came to Goldschmidt from many countries, among them honorary or foreign membership of most of the leading scientific academies of Europe. It is pleasant to remember that in this country his great contributions had been recognized by his electron as a Foreign Member of the Royal Society in 1943 and of the Geological Society of London from whom he received the Wollaston Medal, its highest award. He was invited to deliver the Hugo Müller lecture before the Chemical Society in 1937 and was the recipient of an honorary degree from Aberdeen University. In his own country he had received the Nansen Prize and was made a Knight of the Royal Norwegian Order of St Olaf.

For the appreciation of Goldschmidt's work in the field of crystal chemistry, the writer is indebted to Professor J. D. Bernal, F.R.S., and he owes acknowledgment to Dr I. Oftedal of Oslo for important data on Goldschmidt's life and work in Norway, to Professor M. Born, F.R.S., for information on his period at Göttingen, and to Dr W. G. Ogg, on his period at Rothamsted.

# Commemorative speech on Professor V. M. Goldschmidt at the Mathematics and Science Conference of 14 November 1947*

O. HASSEL

WHEN Victor Moritz Goldschmidt died on March 20 this year (1947), our Academy lost a well-known member, a natural scientist who left a deep imprint on the world of science.

For many years he had instilled in himself a great desire for work, a greater desire than was tenable and, in addition, the strain of the war proved too much for him. When he returned to Norway, in the summer of 1946, he was already a dying man. We felt that, in a way, an important part of science was buried when we realized he was no longer with us. Goldschmidt had represented science in a way true to our best tradition. It is not easy to express the loss our scientific life has suffered by his death at only 59 years of age.

Goldschmidt was not Norwegian by birth, and even though he didn't feel himself to be truly Norwegian, in his work as a geologist and mineralogist he was indisputably so. The foundation built by Th. Kjerulf, W. C. Brøgger and J. H. L. Vogt ensured that Norwegian science was highly respected in these fields. This, along with the nature of the country, ensured that it was not his father's field of science, chemistry, that originally drew him to begin university in Oslo in 1905 at the age of seventeen. But it was chemistry, especially inorganic and physical chemistry, that soon began to interest him strongly, and his insight and knowledge in these fields was impressive. In his later years after his geochemical work had brought him in close contact with the problems of nuclear physics, he threw himself energetically into the study of quantum mechanics.

Goldschmidt's scientific efforts span so many fields that it is unlikely anyone could be found among us who was well acquainted with all of it. His first major work, his thesis, was printed in the Academy's journal in 1911. This work, which dealt with contact metamorphism in the Oslo area, and as has been previously stated (by others), is something out of the ordinary. Although it is based on a great deal of material, each aspect is, nevertheless, carefully documented from both a mineralogical and chemical point of view.

His great petrographic conclusions are based on the principles of physical chemistry and apply far beyond the special conditions of the Oslo area. Goldschmidt's work on contact metamorphism expanded, from 1911 to 1921, into studies which include all the mountains in the south of Norway, as far as the Trondheim area, and contain thorough tests of regional metamorphism. In these works, he introduced the idea of the origins of certain species of rocks which form from genetic and chemical-mineralogical related igneous rocks, and he showed that at least three such types could be identified in the mountains of southern Norway. These works made a considerable impact, especially his studies of the so-called "injection-metamorphism" in the Stavanger region. After Goldschmidt had become the Chairman of the State Raw Materials Committee in the fall of 1917, he concentrated more and more on problems connected with the occurrence of raw materials in the crust of the Earth. The comprehensive scientific investigations he initiated in this regard resulted in important knowledge of the geochemical distribution of the elements. With a few fellow workers, these geochemical projects were continued under his knowledgeable leadership for the next 25 years up until his death. For the first twelve years, until Goldschmidt moved to Göttingen in 1929, he carried out his work at the University's Mineralogical Institute, making it the real home of geochemistry. At this time, X-ray methods were just beginning to be used, for example, to test spectrographic and crystal-structure data. From very generalized data based on extremely precise experimental methods, Goldschmidt succeeded in contributing fundamental ideas to geochemistry and to the theory of the relation between crystal structure and chemical characteristics. It is accurate to say

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* From: *Det Norske Videnskaps-Akademi i Oslo,* Årbok 1947, pp 85–102. Translated by Olaf Niemenn and Bernard Trevor, Alberta Research Council.

that he, more than anyone else, is the creator of crystal chemistry.

Goldschmidt divided the elements into siderophile, chalcophile, lithophile and atmophile, and he succeeded in finding the relations between these divisions and each element's electronic characteristics. Probably the most interesting parts of his works are those which deal with the nature of geochemistry and crystal chemistry in various parts of the Earth. Especially important here is the reduction in the ionic radius of an ion in the lanthanide series (La-Lu) which occurs as the atomic numbers increase. This "lanthanide-contraction" is of great importance in the relations between elements. The knowledge of atomic and ionic radii was of great importance in all later work on crystal structures. Goldschmidt was quick to realize the importance of radius ratios for coordination numbers, and he explained why certain limited values responded to the changes between certain structure types. By also taking into consideration the polarization qualities of single ions it became possible to explain the relation between the configuration of the single atom, its ion and its chemical characteristics. On the basis of this, he improved on theories of isomorphism, polymorphism and morphotropism, and the relations between the physical characteristics of a crystal and its chemical composition.

After Goldschmidt took over the professorship in Göttingen, he set up an institute like the one in Oslo but including, as well, a large and well-equipped department for optical spectrographic analysis. In the years leading up to 1935 he carried out a great deal of specific quantitative analyses on the abundance of the elements in the crust of the Earth, and through the analysis of meteorites, of material from outside the Earth. Important advances in quantitative spectrographic analysis methods were also made during this period.

After his return to Norway in 1935, he published No. 9 of his "Geochemische Verteilungsgesetze der Elemente," printed in the Academy's journal. In this work he used all available data which he considered reliable, whether his own or that of others. He also was concerned with astrophysical, and the newer nuclear-physical data. He tried in one paper to reach as broad and reliable a view as possible on the connections among all the chemical isotopes in the universe. The value of these geochemical studies depended as much upon the reliability of his own experimental contributions as on his critical ability to judge the precision and range of the results of others. His broadly-based knowledge was extremely important here.

Although Goldschmidt's practical work has not become as important as his scientific research, its influence is nevertheless stimulating. In one field he saw for himself the practical results of his work: the use of the Norwegian "olivinsten" (olivine stone) to make fire-resistant materials.

A unique abundance of ideas and daring characterized Goldschmidt's attack on difficult problems. His scientific enthusiasm was, however, controlled by his intelligence and critical judgement. He also had an extraordinary memory.

It is seldom that a researcher can accomplish in one life work which is so versatile and broad, and still possess an inner connection as organic as Goldschmidt's. And he completed all this before he was fifty years old. Then the war came with all its accompanying stress. It is tragic that the events of these later years prevented him from completing the more generalized comments which we know he was going to write. An important part of science has therefore been lost.

The critical common sense which was characteristic of Goldschmidt as a scientist was not always apparent in his judgement of situations and people. This aspect of his person showed a lack of understanding. Often he admired too easily and, even more often, he was too suspicious of the good intentions of others for no apparent reason. He was especially suspicious of one of his co-workers from Göttingen, who was aware of this. The latter wrote in a letter shortly after Goldschmidt's death "But in his heart he was decent." It is certain that many of us have reason to thank him for the unselfish help he gave when he was asked a scientific question.

The position he achieved in scientific circles abroad is unique. One way to observe this is through all the awards he received. But also, on a human level, he made many good friendships with fellow workers from abroad. Norwegians who visit other countries can attest to this.

We honor his memory.