

## 7 / *Geochemistry in Göttingen: 1929–1935*

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DURING THE 1920'S GOLDSCHMIDT received several invitations to professorial posts in European universities. On May 18, 1924 Richard Willstätter, professor of chemistry at the University of Munich (who received the Nobel Prize in Chemistry in 1915 for his work on plant pigments) wrote to him asking whether he would consider being the successor to Paul von Groth as professor of mineralogy. Willstätter describes what happened in his book *From my Life*:<sup>1</sup>

“In the summer of 1924 my old teacher and admired colleague, Paul von Groth, retired from his professorship at the age of eighty-one because of long-standing infirmities of old age which he was just beginning to notice himself. . . . He had already explained to us many years earlier that there was only one man whom he wanted and considered suitable as his successor, though not a product of his school—Victor M. Goldschmidt, who was a son of the respected chemistry professor Heinrich Goldschmidt. . . . Victor M. Goldschmidt was master of scientific fields no less wide in scope than Groth’s, but in different fashion. His gift lay in profound searching by productive experimental work, and he was able to open up such great new fields as modern geochemistry by his widely recognized, trail-blazing researches. Wien (professor of physics and dean of the science faculty) opposed Goldschmidt’s appointment, if not before the assembled faculty, at least individually with most of our colleagues. Eventually he was seen going from place to place in the Academy, preparing the faculty vote. He was dean now and knew how to conduct the discussion along his own lines. Wien would never mention Jews or non-Aryans, but he talked of foreigners. Goldschmidt’s appointment was rejected, although the faculty was unable to make another similarly appropriate nomination. The Ministry appointed a professor from a girl’s high school whom the faculty had not nominated and did not approve of. Groth was profoundly unhappy.

If, in the given circumstances, the faculty was disinclined by a large majority to nominate the only famous scholar who had been

nominated, it was because they did not want a scholar of presumably Jewish descent (or probably partly Jewish, I know nothing about it) in their midst. I announced my resignation on the evening after this vote."

It may be recalled that Munich was the cradle of Naziism, where the party was formed after World War I. Goldschmidt evidently had some misgivings, even before the faculty vote. He wrote to Willstätter ". . . Racial fanaticism is one of the evil phenomena of the present day, and I fear it will spread over the whole world. . . . In the spring of 1914 the choice between Munich and Kristiania would not be in doubt; today I have serious reservations about Munich; no one knows what will be the state of the world in 1934" (translation from German). A truly prescient statement! Willstätter, himself a Jew, was threatened with arrest by the Gestapo in 1938 but he escaped to Switzerland, where he died in 1942.

In the summer of 1925 Goldschmidt received an extremely attractive offer from the Technical University in Berlin. He was promised a minimum salary of 28,000 marks, 80,000 marks for equipment of his institute, four assistants, and an additional professor to relieve him of a large part of the teaching duties. This represented a great improvement on his situation in Oslo, where, in addition, he was increasingly isolated and at odds with his colleagues. His scientific renown, and his success in developing his industrial interests, did not sit well with some of his colleagues in the university community. He was not the most diplomatic of men, and he could denigrate a colleague by a thoughtless comment. Goldschmidt accepted the Berlin offer, but pressure from his mentor and friend Professor Brøgger, and from Gunnar Knudsen, the former Norwegian prime minister, persuaded him to withdraw his acceptance and to remain in Norway.

Goldschmidt's dissatisfaction with his situation in Norway is expressed in a letter to Brøgger dated July 20, 1925:

"When I now, after 16 years of service to the university, find every reason to accept the German invitation, my motivation lies not only in the poor material situation here, but to a large part in the atmosphere of narrow-mindedness, envy, stupidity, and malice among some colleagues, which poisons the scientific life. In such an atmosphere one loses hope at achieving any significant contribution to science or the nation" (translated from Norwegian).

Further offers were not long in coming. Otto Mügge, Professor of Mineralogy at Göttingen since 1908, was to retire in 1928. As a result of an invitation, Goldschmidt wrote to the Rector of the University of Oslo on August 29, 1927, requesting leave from September 3–15 "to negotiate the conditions for assuming the mineralogy professorship in Göttingen." The negotiations were to continue over the next two years. He spent January and February 1928 as guest lecturer in Göttingen.

The University of Göttingen was anxious to recruit Goldschmidt, and the Prussian Ministry of Education offered him facilities far superior to those he had in Oslo. He was to have a Mineralogical Institute built to his specifications, with appropriate staffing of research and technical assistants and adequate financing. The university acquired a former secondary school building on Lotzestrasse and equipped it according to his requirements. Goldschmidt described it as follows:<sup>2</sup>

“When I was invited to Göttingen, the university desired that I should organize a large new mineralogical institute, equipped for crystal-chemical and especially for the geochemical researches which I wished to undertake. Göttingen also offered a great advantage, in that a group of outstanding physicists was interested in collaborative work. I also had the opportunity to promote investigations of industrial importance, such as on refractories for metallurgical use, a subject I was then engaged in.

In Göttingen two buildings were placed at my disposal, a secondary school with an adjoining gymnasium and chemical laboratory. These I had connected with a hall in which the mineral collections were housed [Fig 1 in the original; Plate 17 here]. In the main building the cellar was converted into workshops, a mechanical shop with places for five workers, a carpenters' shop for two men, a laboratory for the preparation of rock and mineral sections, and a high temperature-high pressure laboratory. The library and staff offices were on the first floor; the chemistry section was installed on the second floor, with six laboratories and a balance room; the third floor comprised the X-ray laboratories for crystal structure and chemical analysis. The adjoining building housed lecture rooms and laboratories for teaching mineralogy, petrography, and crystallography, and rooms for research students and visitors. The institute was thus a combined institute for mineralogy, chemistry, and physics, since all three sciences are an essential part of modern geochemical research. In addition we had a small separate building as a rock store and for cutting and grinding. Much of the equipment for teaching and research was made in our own workshops.

The room for X-ray spectrography is illustrated in Fig. 2 [not available]. Some of the apparatus I brought from Oslo and it was installed by my assistant K. Stenvik, who accompanied me the first years in Göttingen. X-ray spectrography is the ideal technique for the analysis of most elements in concentrations greater than 0.1–0.01%, and can be used for lower concentrations if suitable enrichment procedures are available. As examples I mention the work of my Japanese collaborator Dr. E. Minami on the determination of the concentrations of rare earth elements in shales, the first time these elements have been measured in a common rock, and Dr. W. Noll's investigation of the geochemistry of strontium.

The research laboratory for emission spectrography is illustrated in [Fig. 3 in the original; Plate 18 here]. We see three of my research

associates, Dr. H. Hörmann, Dr. H. Bauer, and Dr. L. W. Strock at the large spectrographs specially constructed for our work by Dr. R. Mannkopff. For our researches we required spectrographs with very great dispersion, in order to make photometric analyses of individual lines in the spectrograms" (translated from Norwegian).

After Mügge's retirement and before Goldschmidt's arrival the day-to-day operations of the institute were the responsibility of do-cent (assistant professor) Dr. Friedrich Heide.<sup>3</sup> In March 1929 Theodor Ernst<sup>4</sup> joined the staff of the institute and worked closely with Goldschmidt during his time in Göttingen.

Goldschmidt's father retired as Professor of Chemistry at the University of Oslo at the end of the 1928–29 academic year. There were two candidates for the vacant chair: Ellen Gleditsch,<sup>5</sup> an accomplished radiochemist, and Odd Hassel,<sup>6</sup> who had worked with Goldschmidt on problems of crystal chemistry. Goldschmidt strongly supported Hassel for the position, but the faculty voted to appoint Gleditsch. For Goldschmidt this was the last straw; he immediately resigned his professorship and accepted the Göttingen post. Odd Hassel was appointed Professor of Physical Chemistry at Oslo in 1935 and received the Nobel Prize in Physics in 1969.

Goldschmidt, his father and mother, and their housekeeper, Miss Brendingen, moved to Göttingen in September 1929, to a large Victorian house at Wagnerstrasse 8.<sup>7</sup> His mother died on October 10, 1929.

In 1929 the science faculty of the University of Göttingen was an unparalleled galaxy of talent. The mathematical tradition was carried on by Hilbert, Courant, Landau, and others. The organic chemist Wallach (Nobel Prize, 1910) was living in retirement, and his successor Windaus (Nobel Prize, 1928) was at the height of his career; his colleague in chemistry, Zsigmondy, had received the Nobel Prize in 1925. The Physics Department was guided by the triumvirate James Franck (Nobel Prize, 1925), Max Born (Nobel Prize, 1954), and R. Pohl. Prandtl, one of the founders of modern aerodynamics, was one of Göttingen's great men, as was Tammann, the physical chemist who was still active in retirement. The zoologist Kühn and the astronomer Kienle became great personal friends of the Goldschmidts. This galaxy of talent, alas, was to be cast to the winds after the Nazi takeover in 1933.

After Goldschmidt's death, Max Born wrote as follows:<sup>8</sup>

"When he first came to Göttingen there was a latent tension between us, a mutual doubt regarding our work on ionic crystals: he considered my calculations of lattice energies cumbersome and scarcely worthwhile, and I had no confidence in his primitive way of adding ionic radii. But we soon discovered that these two methods were complementary, one providing exact values in a few simple cases, the other covering the whole field of crystal chemistry. After clearing the air, we became great friends. He was a remarkable

man in many respects. His memory was stupendous. Once I sent an assistant to him to ask about literature on a great number of data. Instead of giving titles of papers, he just dictated the 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, polarizabilities, etc., but also their occurrence in minerals and the distribution of these minerals in the earth's crust. If he did not know a fact, he had simple ways of deriving it from his radii.

Goldschmidt had a very original mind and a great sense of humour which sometimes found expression in a somewhat caustic manner. One had to take the trouble to look below the surface to discover a gentle and most generous nature which was easily wounded, and had no other defence than to hit out. To those who came to understand this, he was a devoted and most loyal friend, and they now mourn for one who had enriched their lives."

Goldschmidt brought some equipment which was his personal property with him to Göttingen, and his personal assistants Kristoffer Stenvik and Mimi Johnson-Høst to help in setting up the laboratories. Felix Machatschki accompanied him as guest lecturer in mineralogy in 1929, leaving in 1930 to become Professor of Mineralogy at the University of Tübingen.

Goldschmidt came to Göttingen in 1929 with great plans for comprehensive investigations on the abundance and distribution of all the chemical elements. His crystal chemistry had elucidated the probable mode of occurrence of the rare elements. In the crystallization of igneous rocks, the rare elements would tend to occur in minerals which would accommodate them in terms of their ionic radii and coordination numbers—in effect, the crystal structures acted as a sorting mechanism, accepting those elements which could be accommodated in specific lattice positions, and rejecting those either too large or too small. For example, nickel is present in minor amounts (up to about 0.4%) in olivine,  $(\text{Mg,Fe})_2\text{SiO}_4$ , because  $\text{Ni}^{2+}$  has practically the same radius as  $\text{Mg}^{2+}$  and  $\text{Fe}^{2+}$ . Elements with ions either too small or too large to be accommodated in the common minerals of igneous rocks concentrated in the residual liquids from magmatic crystallization, which formed pegmatites and quartz veins where the rarer elements were often present as specific minerals.

It was clear to Goldschmidt that classical methods of chemical analysis were inadequate for determining the low concentrations of the rarer elements in rocks and minerals. Even X-ray spectrography, which he had used so successfully in his investigation of rare earth minerals, had a lower level of sensitivity around 0.01% (100 ppm—parts per million). He needed a technique a hundred times more sensitive, down to 1 ppm. He found it in the development of optical spectrography with the carbon arc, a technique known for many years but which had not been applied to the quantitative analysis of rocks

and minerals. He recruited a chemist and a physicist, Clemens Peters<sup>9</sup> and Reinhold Mannkopff,<sup>10</sup> and a talented mechanic and instrument maker, Hermann Albrecht. Peters and Mannkopff refined the technique of quantitative spectral analysis with the carbon arc, and Albrecht built and maintained the equipment. The first application, in 1930, resulted in the discovery of germanium as a common constituent of coal and of the soot and ashes therefrom. A story has it that Miss Brendingen found Goldschmidt on his back in front of the fireplace raking soot out of the chimney, and feared that the professor had gone mad! He found that raw coal could contain up to 0.01% Ge, and the soot and ashes could contain 0.1% or more. One ash, from the Hartley seam in the Newcastle district in England, contained 1.6% GeO<sub>2</sub>, and was later utilized as a commercial source of this element.

When Goldschmidt arrived in Göttingen there were few students in the Mineralogical Institute, because of the long interregnum since Mügge's retirement. His reputation soon attracted talented students and researchers, not only from Germany but also from abroad. Among the distinguished foreign researchers were Harry Berman<sup>11</sup> from the United States (September, 1932–April, 1933), Mosé Balconi from Italy (October, 1932–December, 1933), Vladimir Shcherbina from Leningrad (September, 1932–March, 1933), Eiiti Minami<sup>12</sup> from Tokyo (May, 1933–July, 1935), Lester Strock<sup>13</sup> from Philadelphia (May, 1933–November, 1935), and others such as Thure Sahama from Finland who visited for shorter periods.

During the Göttingen years the geochemistry of many elements was intensively investigated, as follows:

<i>Element</i>	<i>Investigators</i>
Gallium	V. M. Goldschmidt and C. Peters
Scandium	V. M. Goldschmidt and C. Peters
Beryllium	V. M. Goldschmidt and C. Peters
Noble Metals (Ru, Rh, Pd, Ag, Os, Ir, Pt, Au)	V. M. Goldschmidt and C. Peters
Boron	V. M. Goldschmidt and C. Peters
Germanium	V. M. Goldschmidt and C. Peters
Arsenic	V. M. Goldschmidt and C. Peters
Alkali Metals (Li, Rb, Cs)	V. M. Goldschmidt, H. Berman, H. Hauptmann, C. Peters, H. Bauer, H. Witte <sup>14</sup>
Lithium	L. Strock
Strontium	W. Noll <sup>15</sup>
Barium	W. von Engelhardt <sup>16</sup>
Rare Earths (Y, La- Lu)	E. Minami
Chromium	V. M. Goldschmidt, H. Bauer, H. Hörmann

Molybdenum  
Selenium

M. Balconi, H. Hauptmann  
V. M. Goldschmidt, O. Hefter,  
L. Strock, E. Minami

The years in Göttingen, up to 1933, were probably the happiest in Goldschmidt's life. In Oslo he was something of a loner, and had become progressively alienated from many of his university colleagues. In Göttingen he not only inspired his own students but drew inspiration from his colleagues—the physical chemists, inorganic chemists, physicists, astronomers, and biologists. It was an almost ideal cooperation with his fellow scientists, and in addition there was a constant exchange of ideas with foreign visitors and guests.

Among the distinguished visitors to Goldschmidt's institute during the Göttingen years was the noted Russian geochemist V. I. Vernadsky,<sup>17</sup> who at that time was living in Prague. They had known each other for many years (Vernadsky had been a visiting lecturer in Oslo in the 1920's), and corresponded frequently.<sup>18</sup> At Goldschmidt's invitation Vernadsky spent several days in Göttingen in June 1932 and gave two lectures. Goldschmidt's letter to him (April 29, 1932) regrets that it is not possible to offer an honorarium, but asks him to be his house guest. Vernadsky arrived on June 15 and Goldschmidt met him at the railroad station. The meeting was an enjoyable one (Plate 23). After Vernadsky's return to Prague, Goldschmidt wrote (July 16)

"For my father and I your visit to Göttingen was a most pleasant experience, and for my colleagues and students your lectures were of the greatest interest and value. We greatly appreciate your visit, and hope you will return often to Göttingen."

He then goes on to educate Vernadsky on the new developments in crystal chemistry, specifically on the relationship between zoisite,  $\text{Ca}_2\text{Al}_3(\text{SiO}_4)_3(\text{OH})$ , and orthite (allanite), a complex rare-earth bearing silicate mineral. Already in 1911 Goldschmidt had shown that the two minerals were closely related, probably isomorphous. At that time it would have been assumed that the trivalent rare earths replaced trivalent aluminum. The new crystal chemistry developed by Goldschmidt in the 1920's showed that this explanation was improbable, since the ionic radii of the rare earth elements are much greater than that of aluminum. In 1930 Machatschki, working in Goldschmidt's institute, provided the correct explanation—the rare earths replace calcium, and electrical balance is maintained by the concomitant replacement of some aluminum by magnesium, i.e.,  $\text{Ca}^{2+}\text{Al}^{3+}$  by  $\text{La}^{3+}\text{Mg}^{2+}$ . Vernadsky was evidently unaware of these developments, and argued that zoisite and orthite could not be isomorphous because orthite is soluble in acids whereas zoisite is not. Goldschmidt replied by pointing out that, in the isomorphous series of plagioclase feldspars, albite ( $\text{NaAlSi}_3\text{O}_8$ ) is insoluble, whereas anorthite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ ) is soluble in acids. The correspondence on this subject continued for some time; it is not clear whether Vernadsky was ultimately convinced.

Th. Ernst, assistant to Goldschmidt during the Göttingen years, later Professor of Mineralogy at the University of Erlangen, recalls that time:<sup>19</sup>

“How did Goldschmidt organize his day? Before coming to the institute he dictated his more private mail to his secretary at his home in Wagnerstrasse, a large old-fashioned villa where he lived with his father. When he arrived at the institute he would attend to administrative matters, and then (if no lectures or laboratory work were scheduled) he would visit his coworkers. These almost daily rounds showed that the “Chief” was always available to discuss the research work and the researcher’s problems. If one had a problem, a discussion with Goldschmidt frequently provided a new perspective. He welcomed ideas from his coworkers, while examining them critically.

In discussions one could only admire his remarkable memory, not only for the literature (for which he could often give volume number and year) but also for crystal data. If shown a mineral, he would recall where it was described, to the amazement of coworkers and visitors.”

Goldschmidt was an inspired teacher. From the beginning he would be present during the practical work with the petrographic microscope. Naturally, the small number of advanced students learned much from him, but his assistants (Laves<sup>20</sup> and I) learned even more. He prepared his lectures with great care. I was his assistant for some years, and it was not always easy to fill his requests. At first there was almost nothing to illustrate crystal structures. I spent many night hours making models of the principal structure types by glueing together celluloid balls of different sizes, which taught me a lot about the crystalline state. His lectures, so stimulating for the serious student, were delivered in a high-pitched monotone which induced somolence in some; however, he would occasionally animate his listeners with an appropriate joke.

If his instructions were not followed or minor mishaps occurred, as can happen in any institution, he could become very angry and “blow up.” Sometimes he recognized that he had overreacted, and then he would make a diplomatic retreat by the gift of a bottle of schnaps or a packet of cigars. With the women in the institute he was very restrained with his appreciation. I remember once when he appeared several times in the chemistry laboratory with a small packet of candy, but did not hand it to the lady in question until the male staff were no longer present.

As Director, Goldschmidt typified the conscientious civil servant, who saw to it that the budget was prudently and properly administered. Laves and I were largely responsible for implementing administrative directives, which occasionally raised some problems with visiting scientists.

With his academic colleagues Goldschmidt—perhaps because of his conservative political leanings—was closest to the experi-



mental physicist R. Pohl and the geneticist R. Kühn. They often accompanied him on short excursions, when Goldschmidt was at his most relaxed (Plate 28). His relationship with some of his Jewish colleagues was somewhat tense, probably because of differing political views. However, it is typical for his upright attitude that in 1933 he publicly affirmed his Jewish faith.

On his departure from Göttingen in the autumn of 1935, his closest co-workers gathered at the railroad station to say goodbye to him and his father. In spite of his difficult situation, Goldschmidt had retained his position with the justification that he had been entrusted with the institution and should remain as long as the higher administration wanted him. He would probably have been spared much grief, if he had left this now unfriendly land much earlier. We remember him with gratitude. As his students we are proud of our teacher; we appreciate his humanity and regret his comparatively early death" (translated from German).

Goldschmidt was a great animal lover and Paul Rosbaud recalls the situation in Göttingen:<sup>21</sup>

"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 incredibly stupid") another was Richard<sup>22</sup> ("Weil er so stark riecht"), but the most notorious was Magdalena, who came to a sad and untimely end. V.M. [Goldschmidt] 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."

During the Göttingen years Goldschmidt, while directly concerned with the abundance and distribution of the individual elements, was also pondering the wider implications in terms of the geochemical cycle (Fig. 10). He expounded on this in three invited lectures<sup>23</sup> in Stockholm in February 1934 and later in his Hugo Müller lecture to the Chemical Society in London in March 1937.

The geochemical cycle treats the crust of the Earth, together with the associated atmosphere, hydrosphere, and biosphere, as a physicochemical system largely differentiated from the underlying mantle, although receiving from it energy in the form of heat and material in the form of magma. The cycle begins with the initial crystallization of magma, with the formation of igneous rocks, and with the addition of volatile matter to the atmosphere and hydrosphere (magmatic gases consist largely of H<sub>2</sub>O, but with significant amounts of CO<sub>2</sub>, H<sub>2</sub>S, SO<sub>2</sub>, and lesser amounts of other components such as HF and HCl).

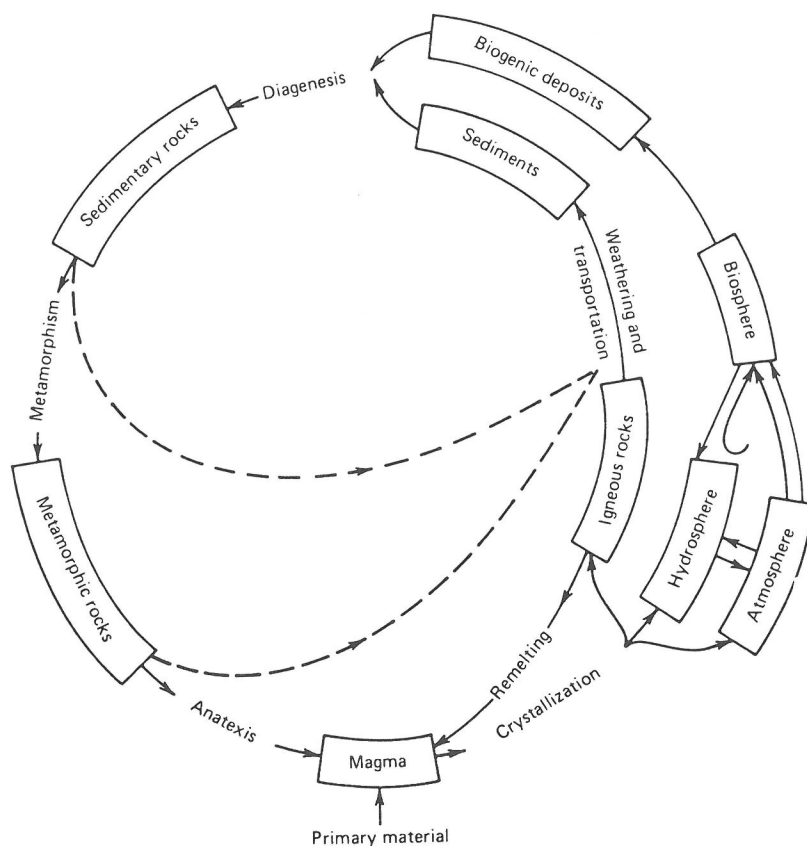


FIG. 10. The geochemical cycle in the outer part of the Earth.

The cycle proceeds through the weathering of igneous rocks and the transportation and deposition of the products as sediments, to form sedimentary rocks. During weathering some elements, such as the alkali metals and calcium, go into solution and are eventually delivered to the ocean. The ocean supports a vast amount of organic life, some of which results in the large-scale deposition of calcium carbonate, to form limestone and dolomite. Land plants convert  $\text{CO}_2$  and  $\text{H}_2\text{O}$  into complex organic compounds, some eventually to form coal and oil. Sedimentary rocks, if buried deeply in the crust, react to heat and pressure to form metamorphic rocks; if sufficient heat is available melting may occur with the regeneration of magma. Goldschmidt's ultimate purpose was to quantify the geochemical cycle and to follow the course of the individual elements in proceeding through the different stages.

His work on crystal chemistry had already provided a fair understanding of the geochemistry of magmatic crystallization. He now proceeded to consider sedimentary processes. He pointed out that this part of the geochemical cycle was critically dependent on reactions taking place in water—weathering is essentially the reaction of water,

together with oxygen and carbon dioxide, with rocks at the Earth's surface. He found that the behavior of an element in this environment could be predicted from its *ionic potential*, defined as  $Z/r$ ,  $Z$  being the charge on the ion and  $r$  its radius, and illustrated this with a diagram (Fig. 11).

The ionic potential of an element largely determines its place of deposition during the formation of sedimentary rocks and is significant in all mineral-forming processes in an aqueous medium. It provides an explanation for the similar behavior of dissimilar elements as, for example, the tendency of the hydrated ions of bivalent beryllium, trivalent aluminum, and quadrivalent titanium to precipitate together during sedimentation. Elements of low ionic potential, such as sodium, calcium, and magnesium, remain in solution during the processes of weathering and transportation; elements with intermediate ionic potential are precipitated by hydrolysis, their ions being associated with hydroxyl groups from aqueous solution; and elements with still higher ionic potentials form anions containing oxygen which are usually again soluble. Hence the division of Fig. 11 into three parts: soluble cations, elements of hydrolysates, and elements of soluble complex anions. For elements of variable ionic charge, the ionic potential will vary: thus iron in the ferrous state is stable in solution, but oxidation to the ferric state greatly increases the ionic potential, and it is then precipitated as ferric hydroxide.

Goldschmidt likened the cycle of matter at the Earth's surface to the separation of the elements in a classical chemical analysis. The chemical differentiation that results is remarkable. The steps in this geochemical separation process are as follows:

1. Minerals that are especially resistant to chemical and mechanical breakdown collect as granular material. Of these the commonest

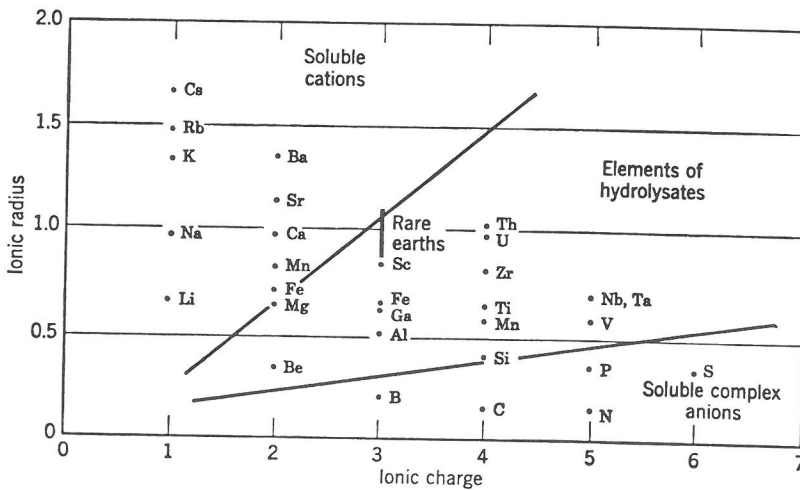
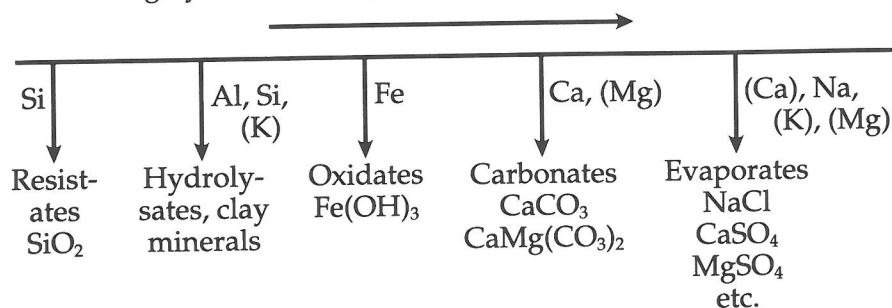


FIG 11. Geochemical separation of some important elements on the basis of their ionic potential (Goldschmidt, *Geol. Fören. Förh.*, vol. 56, p. 409, 1934).

is quartz, and the product is a quartz sand or sandstone showing a concentration in silicon with respect to the parent material. This may be compared to the separation of silica in the first stage of a rock analysis.

2. Accumulation of the products of the chemical breakdown of aluminosilicates, giving a mud consisting essentially of clay minerals. This results in the concentration of aluminum, and corresponds to the second step in a rock analysis, the separation of alumina and other easily hydrolyzed bases.
3. Along with the formation of clay sediments, but often separated in space and time, iron is precipitated as ferric hydroxide. In this process oxidation from the ferrous to the ferric state precedes precipitation by hydrolysis. Concentration of iron is the result, sometimes to the formation of iron ores.
4. Calcium is precipitated as calcium carbonate either by purely inorganic processes or by the action of organisms. Limestones are formed, and calcium thereby concentrated. This may result in practically quantitative separation of calcium, as in a chemical analysis. Limestone can be partly or wholly converted to dolomite by the action of magnesium-rich solutions, and magnesium thereby precipitated and concentrated together with calcium.
5. The bases that remain in solution collect in the ocean, from which they are removed in quantity only by evaporation, giving rise to salt deposits. The most important of these bases is sodium, but lesser amounts of potassium and magnesium also accumulate in sea water.

Goldschmidt depicted the chemical breakdown of a rock by weathering by the following scheme:<sup>23</sup>



The scheme depicts the course followed by the major elements during sedimentation and gives a useful geochemical classification of sediments into *resistates*, *hydrolysates*, *oxidates*, *carbonates*, and *evaporates*. Goldschmidt recognized a further class, the *reduzates*, which include coal, oil, and sedimentary sulfides.

He then proceeded to quantify the sedimentary cycle by some ingenious calculations, i.e., to determine the total amount of igneous rock weathered during geological time and the amounts of the different sediments thereby produced. For each square centimeter of the

Earth's surface, there are 278 kg of sea water; and since sea water contains 1.07% sodium, the 278 kg contains 2.975 kg of sodium. The average sodium content of igneous rocks is 2.83%, and of sedimentary deposits approximately 1%. In the process of weathering a certain amount of the material is removed in solution, and Goldschmidt estimated that the mass of the sedimentary deposits is 0.97 of the igneous rocks that gave rise to them.<sup>23</sup>

Let  $X$  be the amount of igneous rock eroded per  $\text{cm}^2$  of earth's surface.

Let  $Y$  be the amount of clastic sediments deposited per  $\text{cm}^2$  of earth's surface.

Then:  $Y = 0.97X$ .

$$\text{Sodium content of igneous rock per cm}^2 = \frac{2.83}{100} \times X$$

$$\text{Sodium content of clastic rock per cm}^2 = \frac{1}{100} \times Y$$

But the sodium content of ocean water per  $\text{cm}^2 = 2.975$  kg.

$$\therefore \frac{2.83}{100}X - \frac{Y}{100} = 2.975$$

$$\therefore X = 160 \text{ kg/cm}^2$$

$$Y = 155 \text{ kg/cm}^2$$

He then used a similar type of calculation to determine the amount of calcium carbonate and dolomite in sedimentary rocks and obtained the following figures: 10.17 kg  $\text{CaCO}_3$  and 4.37 kg  $\text{CaMg}(\text{CO}_3)_2$ . Hence the total amount of sedimentary rocks per square centimeter of the Earth's surface is 155 kg clastics, 10.2 kg limestone, and 4.4 kg dolomite.

Goldschmidt now proceeded to apply these results, and data on the abundance and distribution of individual elements, to a consideration of the geochemistry of the hydrosphere, specifically sea water, which comprises over 98% of the mass of the hydrosphere. He examined the balance between supply and removal of several elements in sea water. The basis of his comparison was the total amounts of different elements supplied by weathering and sedimentation during geological time. His calculations showed that about 160 kg of igneous rocks have been weathered for each square centimeter of the Earth's surface. Since there are 278 kg ocean water per square centimeter, approximately 600 g of rock have been weathered for each kilogram of water in the oceans. This 600 g of rock have therefore been the potential source of the dissolved matter supplied by weathering to 1 kg of sea water. Of course, only a part of this 600 g has actually dissolved and remained in solution. Goldschmidt drew up a "balance sheet" relating the potential supply of several elements in 600 g of igneous rock to the amounts present in 1 kg of sea water (Table 5).

Table 5. Balance of some elements per kilogram of sea water (Goldschmidt, *J. Chem. Soc. (London)*, p. 666, 1937).

Element	Supplied	Present	Percentage
B	2.4 mg	6 mg	250
Cl	0.29 g	19.3 g	6655
S	0.3 g	0.88 g	293
I	0.18 mg	0.05 mg	28
F	150 mg	1 mg	0.7
P	470 mg	0.06 mg	0.013
Na	16.8 g	10.7 g	64
K	15.0 g	0.37 g	2.5
Mg	12.6 g	1.3 g	10
Sr	250 mg	10 mg	4
Ca	21.6 g	0.42 g	2
Al	52.6 g	0.6 mg	0.0011
Si	160 g	1 mg	0.0006
Pb	10 mg	5 $\mu$ g	0.5
Se	0.4 mg	4 $\mu$ g	1
As	3 mg	20 $\mu$ g	0.7

The most striking feature of Table 5 is that the concentrations of a few elements are far greater than can have been supplied by weathering. These are the common anions of sea water—chloride, sulfate, and borate. Either they were present in great amounts in the primeval ocean or they have been supplied largely from volcanic gases and thermal springs throughout geological time. Judging from the data on amounts and composition of igneous exhalations, the latter alternative is adequate to explain at least the major part of these “super-abundant” elements in sea water.

Ionic potential is important as a measure of behavior of an element in aqueous solution, but the data in Table 5 show that other factors must be significant in the ocean. Thus, of the alkali elements, which all have low ionic potentials, only sodium remains to any extent in the sea; little potassium is present, because it is largely removed by reaction with clay minerals to form mica. The alkaline earth elements are also largely removed from sea water. Biological activity is, of course, responsible for the extraction of much of the calcium. The very small amounts of trivalent and quadrivalent elements in sea water evidently reflect their high ionic potentials, causing them to be almost quantitatively precipitated.

A remarkable feature is the very low percentage of certain poisonous metals and metalloids in sea water, including some, such as selenium and arsenic, which form soluble complex anions and therefore might be expected to accumulate. The quantities of these elements potentially supplied to the ocean during geological time are so great that a serious poisoning action would have resulted had not some

process been active in eliminating them. Goldschmidt suggested that they have been removed from solution by a process similar to that used in practical medicine, that is, adsorption on freshly precipitated ferric hydroxide. He demonstrated the truth of this suggestion by finding that sedimentary iron ores show considerable concentrations of selenium, arsenic, and lead.

Table 6. Annual turnover of CO<sub>2</sub> per sq. cm. of the Earth's surface (1  $\gamma$  = 10<sup>-6</sup> g). Goldschmidt, *Geol. Fören. Förh.*, vol. 56, p. 415, 1934.

	$\gamma$
+ Addition of juvenile CO <sub>2</sub>	3-6
+ Combustion of coal and oil	800
+ Respiration and putrefaction	ca. 40,000
- Photosynthesis	ca. 40,000
- Weathering processes	3-4
- New carbonaceous sediments	0.3-2

Goldschmidt chose to illustrate the geochemical cycle by drawing up a balance sheet for the yearly turn-over of carbon dioxide (Table 6 and Fig. 12). Carbon, although not one of the most abundant elements in the Earth, plays a most important role in geochemistry, because carbon compounds are essential for every known form of life. The geochemistry of carbon is closely linked with that of the other essential elements of organisms, especially hydrogen, oxygen, nitro-

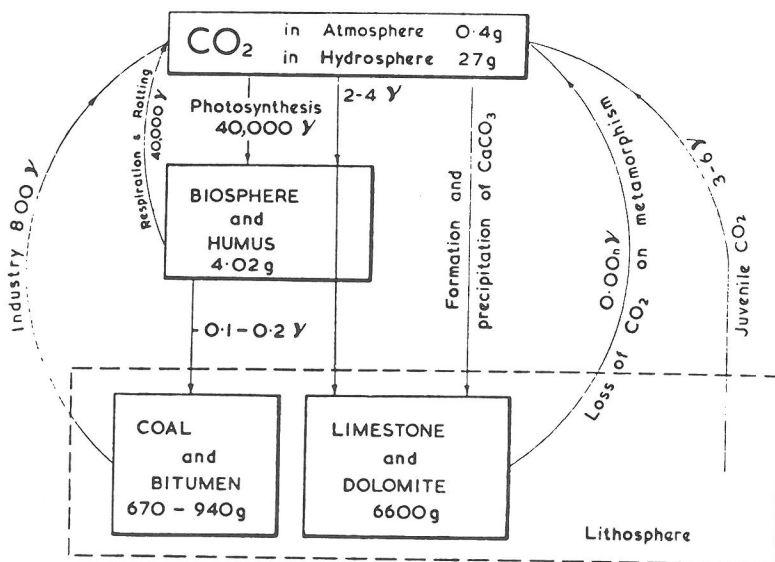


FIG. 12. The geochemical cycle of carbon (1 $\gamma$  = 10<sup>-6</sup> gram); after Goldschmidt, *Geol. Fören. Förh.*, vol. 56, p. 416, 1934).

gen, and sulfur. His balance sheet shows how overwhelmingly the cycle of carbon is determined by biochemical reactions.

He showed remarkable foresight when, in 1936, he anticipated the significance of man-made carbon dioxide emissions, in the following statement:<sup>24</sup>

“The carbon cycle is of especial interest because it demonstrates the great significance that the industrial combustion of coal and other fuels has already had on the carbon dioxide content of the atmosphere. The amount of carbon dioxide which each year is added to the atmosphere by the combustion of fuels is two hundred times greater than that contributed by the world’s volcanoes. This demonstrates that human activity in our time is a highly important geochemical factor” (translated from Norwegian).

What might he say today?

The peaceful and productive lives of the Goldschmidts, father and son, were fundamentally changed and their work interrupted by Hitler’s accession to power in 1933. V. V. Shcherbina, who was working with Goldschmidt at that time, described the situation as follows:<sup>25</sup>

“The Fascist putsch of March 1933 strongly influenced the work of the institute in a detrimental way. Several coworkers left the institute. I was a witness to the occurrences several days after the Fascist takeover, when a group of brownshirts with red bands and swastikas on their sleeves surrounded the institute and attempted to occupy it. “We don’t fight with you” answered Goldschmidt’s deputy Laves (Goldschmidt was not in the institute at that time). The Fascists wanted to hang their flag on the institute; this they did, and during this act they expressed their anger since, when they entered, the institute coworkers met them with cold silence. When Goldschmidt returned to the institute he considered the Fascist flag on his institute as a personal affront. “How glad I am for you, dear colleague” he said “that after a few days you will return to your comfortable Leningrad” (original English).

Following the Nazi takeover, Goldschmidt and his father, who had not previously belonged to any faith, ostentatiously joined the small Jewish community in Göttingen. He considered it his duty, in the interests of his students and co-workers, to continue his work at the university for as long as possible, although he realized he might be dismissed at any time. His sense of humor became grimmer than ever. When Hitler came to power he pronounced that “heads must roll”. Goldschmidt appeared at a meeting with his hair cut more than usually short. When asked why, he tapped his head and said “Damit es besser rollen kann” [“So that it will roll more easily”].

Already by May, 1933, Goldschmidt’s position was becoming difficult, as shown by the following letter from Adolf Windaus (1876–



1959, Professor of Chemistry in Göttingen, 1915–1944) to the Curator (Rector) of the University of Göttingen:<sup>26</sup>

“I am grateful that you remain here, so that we have a man in Göttingen to whom one can turn for help and advice. Professor Goldschmidt has informed me in great distress that some members of the inorganic section of my institute have demanded a boycott of his lectures and laboratories. He named especially one Schorstein, a doctoral candidate of Professor Jander.

I wish I could take serious action against this man. I believe, however, that this would only lead to my own departure, and I will try to remain here for as long as it is still possible.

I ask your advice or your instruction as to how I should proceed. Till now I have always forbidden any sort of political activity within the institute; such a prohibition seems no longer possible” (translated from German).

Goldschmidt was to have been a guest at the International Geological Congress in Washington, D.C., in July 1933, and to have given two invited lectures, but the political developments in Germany prevented this. Later he was invited to be the George Fisher Baker Non-Resident Lecturer in Chemistry at Cornell University but was unable to take it up. He never visited North America, although he had many friends and acquaintances in the United States and Canada, and extensive business dealings with the Harbison–Walker Refractories Co. in Pittsburgh.

By 1935 his situation was becoming unbearable, as indicated by a letter from the NSDAP (Nazi) Gauleitung (local administration) to the University of Göttingen:<sup>27</sup>

“The Gauleitung must deny the request of Professor Dr. Goldschmidt for permission to give a lecture at Lund University in Sweden. Today it is obvious that when a distinguished scientist gives a lecture in a foreign country he will be questioned concerning political developments in Germany. On account of his Jewish mentality Professor Goldschmidt is unable to consider these matters as we would wish, and his judgement is thereby distorted. For that reason the Gauleitung cannot approve Professor Goldschmidt’s proposed visit to Sweden” (translated from German).

The conditions under which Goldschmidt left Göttingen in 1935 were explained in his letter in response to a query by a friend, Dr. J. Shearer of the Physics Department of the University of Western Australia. Goldschmidt wrote:

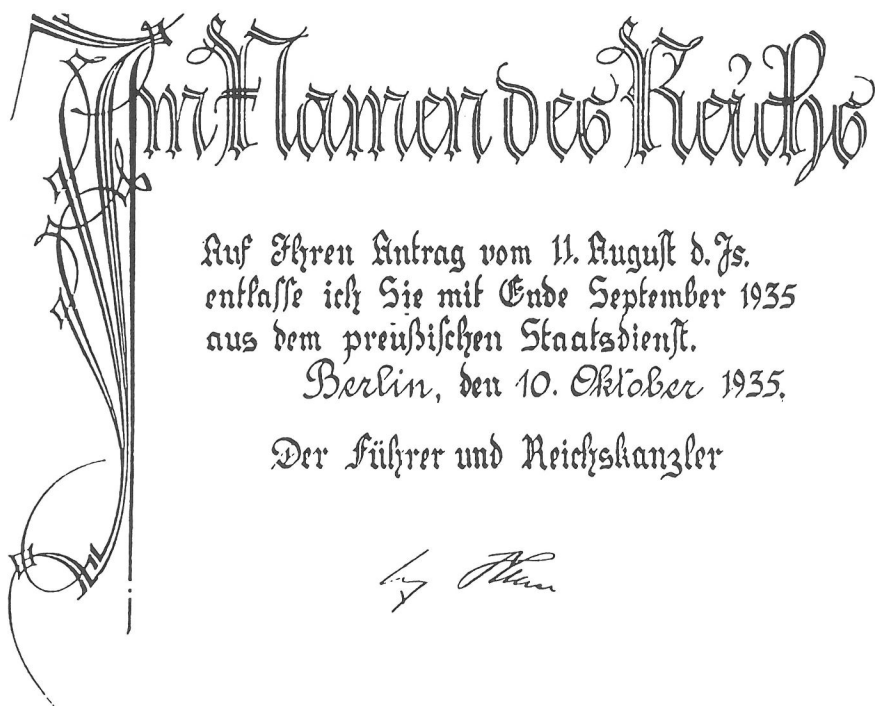
. . . “It is not true that life was rendered unendurable and work impossible for me at Göttingen. The authorities of the University of Göttingen during all my stay in Germany always treated me in a most pleasant and agreeable manner, giving me any facilities of scientific work, nor had I any difficulties with assistants, students, colleagues, officials or others. But you will understand that the gen-

eral attitude against non-Aryans was felt by me as a very great misfortune, even if not in any case used against me personally. In spite of my feelings, which you can understand, I have felt it to be my duty towards science, towards my coworkers at the institute and towards the university to keep my work at Göttingen going on, through the years 1933, 1934, and until summer 1935, an attitude which was encouraged in every manner by all authorities which had to do with my work. I can mention that funds for my laboratories even in that time generously were placed to my disposal, and teaching and cooperation with my colleagues went on in a most friendly manner. However already in 1933 I found it to be my duty to resign from the chairmanship of "Gesellschaft Deutscher Naturforscher und Aertze, Naturwissenschaftliche Hauptgruppe" (corresponding to your "British Association") to make it clear for all concerned that I did not wish to consider myself a representative of science at the same time when my colleagues were driven from their positions, which like myself were non-Aryans.

Then in spring 1935, on May 1 there was placed in Göttingen a big sign board, not far from the road to my institute, with the inscription "Jews not desired". I gave notice that I was resigning my professorship if such board was not taken off, as I could not reconcile my presence in Göttingen with such an open attack against Jews in the same town. Before 24 hours had gone the thing had been taken off. However several months later (in August) a sign-board of the same kind was reerected, that time just opposite my institute. I renewed my action of protest, and that time it was not removed even at my request, as such boards at the same time had been placed in all German towns by direct order of the uppermost party rulers. Consequently next day, August 11, as an ultimate protest I resigned my position, and designated my intention to leave the country.

I may mention, that all negotiations have been made in a most friendly manner and that the authorities of the University in every conceivable manner supported me in order to make agreeable terms for my emigration back to Norway when they learned that my decision could not be moved. However, as you will understand, under existing financial restrictions in Germany, my father and I had to leave at that time all our financial resources in Germany, but we were allowed to take back to Norway all our furniture, library and my instruments for research. Later on I even have obtained uncommonly favorable conditions—as compared with other cases—for transferring even a certain percentage of my financial resources back to Norway. Of course my emigration in 1935 did involve a great financial risk for me, resigning my position and having no other position in another place in expectance.

That my departure from Göttingen, even in being an action of protest from my side, was effectuated in a friendly spirit you may



Entlassungsurkunde  
für den ordentlichen Professor  
Dr. Victor Moritz Goldschmidt  
in Göttingen.

FIG. 13. Dismissal letter for Professor Dr. Victor Moritz Goldschmidt, signed by Hitler and Göring.

learn from the fact that my whole laboratory, including students, assistants, artisans, officials gave a festival for me before I left, and that ever since my departure there has been friendly cooperation between my former institute at Göttingen and my new institute in Oslo, even exchange of assistance and scientific cooperation.

Of course I feel very heavily the injury done to my colleagues, which are non-Aryans as am I, but I feel it necessary to say the

fact that I myself always have been treated in a friendly and correct manner by all authorities, even if it was not agreeable to live in a place where people of my own race were injured and prosecuted only for the sake of their race. When that came to a certain limit, as told above, I resigned my professorship as a protest against iniquity. I feel sure that anybody in my case would have done the same, perhaps even earlier than I did.

My small dog, Bazi, had to be left at Göttingen, as there are very close regulations in Norway against imports of dogs, in order to avoid rabies to be introduced into the country. Bazi is staying at Göttingen with the family of a dentist, and is reported to be a happy, but still rather naughty dog there" (original English).

On August 25, 1935, Goldschmidt travelled to Berlin, where he received a Norwegian passport from the Norwegian Embassy (when he accepted his professorship at Göttingen he had automatically become a German citizen, as a civil servant). Together with his father and Miss Brendingen, he left Göttingen for Norway on September 6. He later received an official document, signed by Hitler and Göring. . . . "At your request of August 11 I release you at the end of September 1935 from service to the Prussian state" (Fig. 13).