Rediscovery of the Elements

A Travelogue of Rediscovery Sites

PART 2

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This is a continuation of a review of "Rediscovery" episodes, initiated in the previous issue (Spring 2017) of *The HEXAGON*. This series includes the visits to mine sites taken by Jim and Jenny Marshall over the ten-year period of 1999–2008. The present issue is exclusively devoted to Sweden, which boasts more discoveries (of the natural elements) than any other country.

Yttrium, etc.

LEFT: Figure 2. The Ytterby mine itself (N59° 25.60 E18° 21.18) is blocked by cave-ins and cannot be entered; the entire area and is covered with heavy foliage.

Figure 1. Entrance to the Ytterby Mine area. The entrance sign describes how the mine produced quartz and feldspar for the porcelain trade.

Yttrium, etc.[1g,j,k,2] Nestled in the Stockholm Archipelago, 20 kilometers northeast of the city of Stockholm is the island of Resarö, an island measuring 3 kilometers across. Ytterby, a small village on the south side of this island, boasted a mine (Figures 1, 2) which produced high quality quartz and feldspar (Figure 3) for the porcelain trade in Great Britain and Poland during the 1700s and 1800s. A "heavy black stone" procured from this mine was analyzed by Johan Gadolin (1760–1852) at Åbo, Finland (now Turku), who isolated the element yttrium in 1794. This dark stone, whose formula is $FeBe_2Y_2Si_2O_{10}$, was subsequently named gadolinite. (Figure 4).

RIGHT: Figure 3:. On the treacherously steep talus slope of the Ytterby mine, specimens of quartz and feldspar, as well as other incidental interesting mineral specimens, can be found.

Cobalt

Figure 5. Old home of Georg Brandt, about a kilometer east of Riddarhyttan. There were actually two—father and son—who lived here. The father sold his pharmacy business in Stockholm in 1680 and purchased the property; the son (who was to discover cobalt) was born here and became a world traveler, eventually settling in Stockholm where he did his important chemical work, but frequently visiting the Herrgård (Swedish manor; N59˚ 49.66 E15˚ 33.12) where he maintained both a financial and scientific interest. The Brandts were very wealthy, producing copper for the king to help finance the nation's expansionist policies.

ABOVE: Figure 4. On the cliff above the Ytterby mine, a marker has been erected by the American Society of Metals (International) which announces the mine has been proclaimed a historical landmark: "Four new elements—yttrium, terbium, erbium, and ytterbium—were isolated from the black stone gadolinite mined here, and were named after the Ytterby Mine." The yttrium (Y) in gadolinite is commonly substituted in naturally occurring minerals by the "heavy rare earths" (right-hand side of the rare earth series in the Periodic Table). In addition, holmium, thulium, gadolinium, and tantalum were also isolated from gadolinite from this mine. Near the mine various streets ("vägen" in Swedish) have been named "Ytterbyvägen,""Yttriumvägen,""Terbiumvägen," "Gadolinitvägen," "Gruvvägen," "Fältspatvägen," "Tantalvägen," and "Glimmervägen" [Gruv = mine; fältspat = feldspar; glimmer = mica].

Cobalt.[1a] In the center of Sweden, 150 kilometers west of Stockholm, lies the village of Riddarhyttan, a community which boasted a thriving copper industry during the 18th and 19th centuries. The town today is surrounded by beautiful woodlands and lush meadows, but as one drives through the countryside there are huge tracks of barren lands which have lost their vegetation to the sulfur dioxide fumes produced by the charcoal roasting of copper sulfides in huge earthen kilns.

One of the successful copper business men was Georg Brandt (1694–1768), Assay Master of the Stockholm Mint. About his old homesite (Figure 5) today are rolling hills and dense forest dotted with ancient copper mines (Figure 6). A byproduct of one these mines was a strange metal which, in contrast to copper, was magnetic. Brandt presented a publication of this new metal in 1748.[1g]

Figure 6. This is the old Pellugruvan Mine (N59˚ 49.64 E15˚ 33.0), one of the more prolific copper mines, and most likely the source of the cobalt ore from Brandt isolated the new metal. These flooded mines and other hidden pits are common about the Brandt estate and pose a danger to children—the entire area is fenced off and not accessible to the general public. In the late 1800s a huge vein of rich cobalt ore (3.5 tons) was discovered 55 meters below ground level.

Figure 7. The entrance to the Bastnäs Mine (N59˚50.75 E15˚35.34), the original source of cerium. This mine dates to over three hundred years. In the early years, the ore was hauled out in winter, when transportation of the heavy load was facilitated by sledding over the frozen ground.

Cerium and Lanthanum

Figure 8. Standing on the talus (waste) pile at the entrance of the mine are Bengt Högrelius (right), a local guide and expert on mineral of the Bastnäs region and his son Anders (middle), also an active geologist. They are presenting a special mineral bastnäsite (a rare earth carbonate) to the author (JLM, left) which they found at the mine. The authors analyzed the crystal when they returned to the U.S. and found it to contain 26% lanthanum, 29% cerium, and 6% neodymium, with lesser amounts of several other light rare earths.

Cerium and lanthanum, etc.[1a,j,k,] In addition to copper industry Riddarhyttan region, iron production was historically even more important, dating back as early as 500 B.C., and large blast furnaces were constructed and utilized half a millennium ago. Huge lodes of hematite (iron oxide) lay about Riddarhyttan. Perhaps the most prominent iron mine was the Bastnäs Mine (Figure 7), 2 kilometers northeast of Riddarhyttan.

A special gray mineral was discovered at this mine in 1751 which was called "the heavy stone of Bastnäs"). This mineral, now known as "cerite," had the complex formula $(Ce,La,Ca)(Mg,Fe)(SiO_4)_6(SiO_3OH(OH)_3)$. In 1803 cerium was discovered by Jöns Jacob Berzelius (1779–1848).[1f] Chemists were surprised when in 1839 Carl Gustaf Mosander (1797–1858) showed that cerium actually contained an additional element, which he named "lanthanum" after the Greek word for "hidden."[1a,j,k] This discovery of Mosander led to further research where more rare earths, all with similar chemical properties and difficult to separate from one another, were discovered by various chemists over the next century.

Our hosts at the Bastnäs Mine were local volunteers (Figure 8) who maintain the area as a special park. In Sweden the "park system" is a general system of volunteers who work to preserve the history and culture of Sweden.

Tungsten and

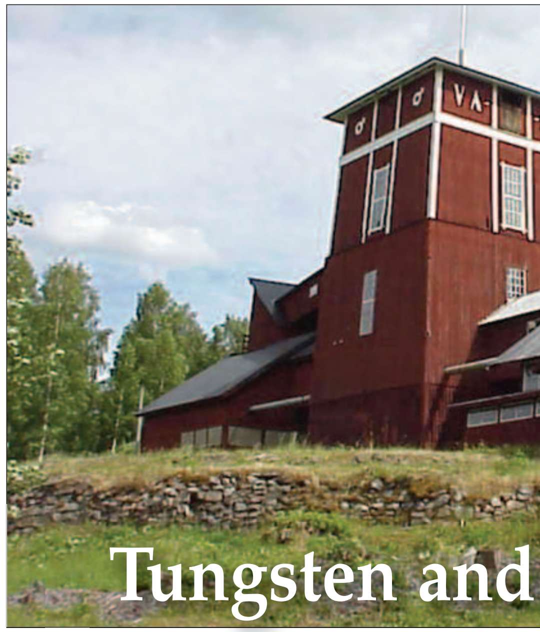


Figure 10. In addition to interesting minerals, the southern face of Bispberg Klack is well known to Swedish botanists as a "sydväxtberg" ("south plant mountain") for its unusual flora.

Tungsten, molybdenum.[1e,h] These elements were discovered by Carl Wilhelm Scheele (1742–1786) who isolated them from scheelite ($CaWO_4$) and molybdenite (MoS_2) procured at the Bispberg Klack (N60˚ 21.44 E15˚ 48.92) (Figures 9,10), a mountain in central Sweden (N60˚ 21.67 E15˚ 47.55). An old iron mine (Bispberg Gruvan) (Figure 11) is the locality where the scheelite ($CaWO_4$) and molybdenite (MoS_2) were procured by Cronstedt for his analyses (Figure 12).

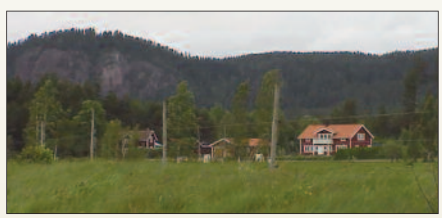
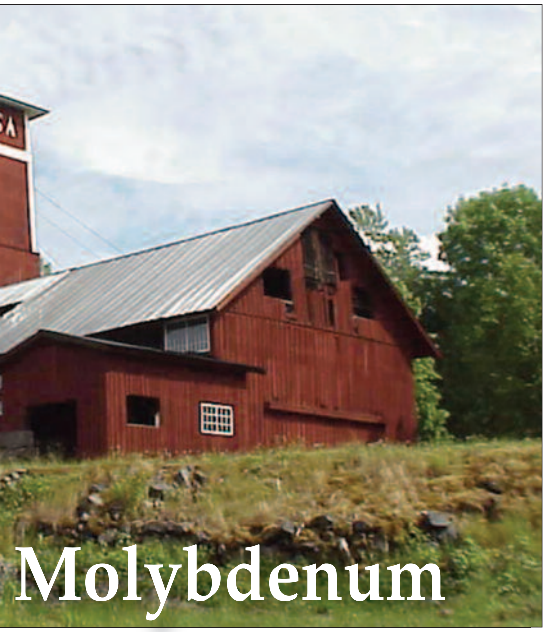


Figure 9. Bispberg Klack ("klack" means "heel" or "platform"). With a sheer granite wall, this mountain looms 130 meters above the surrounding plain. The house is painted with Falun red paint.



ABOVE Figure 11. The Bipsberg Mine, closed down in 1967, had furnished iron ore for more than 500 years. The alchemical symbol for iron ( ) is displayed on the mine tower. The red color discloses the use of Falun red paint (see Figure 15).

Figure 12. For their elemental collection, the authors procured authentic samples of scheelite and molybdenite from Ingemar Johansson of Kopparberg (30 kilometers west of Riddarhyttan). Ingemar was a well-known mineralogist, not only in the Swedish community but also globally. In his basement he had a massive collection of important minerals from across Sweden. He passed away 24 March 2001, leaving a rich legacy for all scientists. The scheelite sample was the typical amorphous form, which was colloquially called "fruset snor' by Swedish geologists, meaning "frozen snot," which accurately described its appearance.

Lithium.[1f] The source of the original lithium minerals was Utö, a 12-km long island in the Stockholm archipelago, 45 km south of Stockholm. One can reach Utö by a 40-minute ride on a commuter boat from Stockholm, conveniently located at a dock at Södra Blasieholmshamnen. directly in front of the Grand Hotel Stockholm. The landing dock at Utö welcomes one to "Utö Gästhamn" which means "Utö Guest Harbor" (Figure 13). A short walk takes one to a historical museum and an overlook into the mine, which now is a flooded quarry. This is quite possibly the oldest iron mine in Sweden, yielding iron ore since the 12th century. It closed down in 1879.

In this mine were discovered two white crystalline minerals, spodumene ($LiAlSi_2O_6$) petalite ($LiAlSi_4O_{10}$), samples of which could be purchased in the museum. The analysis itself was done by Johan August Arfwedson (1792–1841), a student of Berzelius. Arfwedson performed the work in Berzelius' "kitchen laboratory" in his apartment in Stockholm.[1f] The discovery of lithium involved the very meticulous analysis of these minerals by Arfwedson, who showed the "missing weight" was actually due to a very light weight element (Li is the lightest alkali metal).[1i] Previously this discrepancy was ignored by less careful chemists, who attributed it to "experimental error" or "expelled water."

Figure 13. The dock at Utö (N58˚ 58.23 E18˚ 19.51), which enjoys a boat commute twice a day from Stockholm and surrounding islands. The museum (N58˚ 58.02 E18˚ 19.75) and mine (N58˚ 57.98 E18˚ 19.78) are only 300 meters up the hill, behind the dock.

Figure 14. The famous Falun copper mine (Falu Koppargruva) is a huge pit with accompanying shafts. It is reached on Gruvgatan ("mine street") with a large museum, where arranged visits made be made to the depths of the mine by tourists. The Falun Mine is the oldest copper mine in Sweden, beginning production in the 13th century and ceasing production in 1992. At one time the mine was furnishing a majority of copper for Europe's needs. The alchemical symbol for copper can be seen on the tower. Falu Gruva is a World Heritage Site.

Selenium.[1f] This element was discovered in copper ore taken from the huge and historic Falun Mine (Figure 14),[1d] 200 kilometers northwest of Stockholm. The mine had been active for over seven centuries, and furnished much of the financing of the Swedish expansionist policies of the 1600s. (Figure 15) The analysis that led to the discovery of selenium was done by Berzelius at the sulfuric acid works at Gripsholm, 55 kilometers west of Stockholm.

Figure 15. The entrance to the Falun Mine (N60˚ 36.01 E15˚ 36.95). The side buildings are painted with Falun Red paint (Swedish = "Falu rödfärg"), prepared by mixing water, rye flour, linseed oil, and Falun mine residues containing mostly iron oxide. Above the door are a number of alchemical symbols for various elements and salts (see inset, lower left). A resplendid museum (above ground) holds great interest for visitors. Tours may be taken to the huge frigid underground (5˚C); visitors must wear water-proof capes and hard hats.

Figure 18. The Nickel Monument (N61˚ 44.48 E15˚ 09.68), erected in 1971 by Olof Hellström, is next to the country store in the small, isolated village of Los (old spelling Loos).

Figure 16. The Magic Mountain (N57˚ 40.73 E14˚ 04.93), looming 140 meters above the surrounding plain, is composed of magnetite, Fe_3O_4. At a lodge at the top, one can order a drink or a light lunch, and displays can be viewed which describe the history of the mining region.

Vanadium.[1b,c,d] This element was originally recognized as a new metal in Mexico (then a colony of Spain), by Don Andres Manuel del Río (1764–1849) in 1801. His new metal, which he called "erythronium,"[1b] was erroneously discredited by the European scientific community.[1c] Nils Gabriel Sefström (1787–1845) of the Falun Mining School (vide supra) "rediscovered" the element and named it vanadium.[1d] He isolated the element as an impurity in the iron of the "magnetic mountain" in Taberg, located in Småland in south-central Sweden, 300 kilometers southwest of Stockholm (Figure 16). The area is biologically interesting, with unique species of flora and fauna—Carl Linnaeus, whose home was near by, visited the area in 1741 and declared the mountain "One of Småland's [biological] miracles, the likes of which is not to be found in the whole of Sweden."

Figure 17. Chunks of magnetite have broken off the Magic Mountain and litter the grounds below. A magnet has no problem in lifting one of these shards. (The other common oxides of iron, Fe_2O_3 and FeO, are not magnetic). Magnetic compasses gyrate wildly while strolling through the Taberg area.

Figure 19. The original mine and its associated museum, is open during the summer months (N61° 44.52 E15° 09.40). Surrounding the museum are old shafts hidden by vegetation, all surrounded by fences to prevent accidents of nasty falls. Mining ceased in the early 1900s. Today one can take a tour deep into the mine where the cobalt ore had previously been found. When the authors took the tour, their Geiger counter was activated strongly at a level only 20 meters below the surface, attesting to the ubiquity of uranium ore which can be found in almost anywhere.

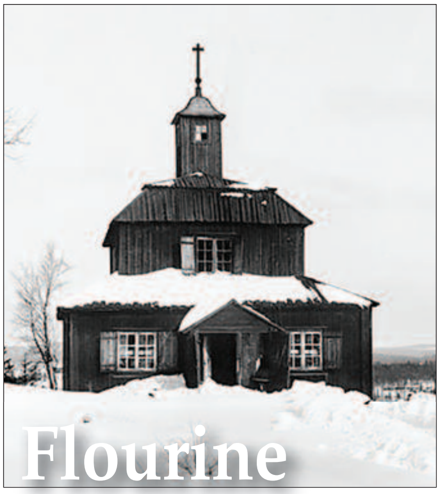


Figure 20. This historic chapel at Garpenberg (Kapellvägen, N60° 18.50 E16° 11.20) is the only architectural remnant dating from the time of Scheele who discovered fluorine (hydrofluoric acid) from fluorite obtained from the nearby mine. A small mining museum resides on the upper floor of the chapel. [credit: Thorvald Gehrman, Public Domain, https://commons.wikimedia.org/w/index.php?curid=16881047].

Nickel.[1h] Axel Fredrik Cronstedt (1722–1765) discovered this element in a cobalt mine in Los, 320 kilometers northwest of Stockholm. Cronstedt may considered the "father of modern mineralogy" by first organizing them on the basis of chemical composition, and a monument has been raised in his honor in Los (Figure 18). A kilometer away, the original mine with an museum can also be visited (Figure 19). Cronstedt was intrigued by nickel ore, which superficially acted like copper—it was red-brown and oxidized green—but would not yield copper, and hence was called "copper devil" ("Kupfer-nickel," German for "copper-devil"). Chemistry explains the strange behavior of nickel ore—nickeline (NiAs) is red brown but oxidizes to green annabergite ($Ni_3(AsO_4)_2 \bullet 8H_2O$).

Manganese, chlorine, oxygen, barium—miscellanous elements obained by the use of pyrolusite.[1e] The exact source of pyrolusite (MnO_2) for the discovery of these elements is not known; this mineral is widespread throughout the world; in Sweden, it is found, for example, in Taberg (see above) The name itself (from Greek) means "fire-wash," alluding the fact that it was found to decolorized glass, known since the Renaissance Venetians.

Manganese was discovered in 1774 by Johan Gottlieb Gahn (1745–1818) at the Falun Mining School in Falun (Falu Bergskola), one kilometer east of the mine in the center of Falun. An exhibit on Gahn can be found at the Falun Mine Museum (see above). Gahn prepared the element by reducing pyrolusite (MnO_2) with charcoal.

Chlorine, oxygen, and barium were discovered by Scheele while he was working in various apothecaries in Sweden—gaseous chlorine by reacting pyrolusite with hydrogen chloride (1774); oxygen by treating pyrolusite with sulfuric acid (post-1771); and barium as an impurity in pyrolusite (1774).

Fluorine.[1e] Although solutions of hydrofluoric acid were used in glass etching since the beginning of the 16th century, Scheele first recognized hydrogen fluoride (1771), calling it fluss spath syran (fluorospar acid = fluorospar), by reacting fluorospar (fluorite, CaF_2) with sulfuric acid. The fluorite he used was obtained from Garpenberg (N60° 18.55 E16° 11.53), originally an iron mine dating from the 13th Century. The mining complex is still active, modern and huge, producing several metals, predominately zinc. Difficult to locate on a lonely dirt road is a chapel/museum dating from the historic mining days of Garpenberg centuries ago (Figure 20).

NEXT ISSUE: The Travelogue series continues with other countries in Europe.

References

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2. J. L. Marshall and V. R. Marshall, *J. Chem. Ed.*, **2001**, *78*, 1343–1344.

As announced in previous issues of *The HEXAGON*, the Digital Library at the University of North Texas has successfully scanned all of the "Rediscovery" issues published in *The HEXAGON* since its beginning in 2001, and has placed these articles on line for the general public.

This service will continue indefinitely.

In addition, the UNT Digital Library, in conjunction with Jim Marshall, has recently developed a method of presenting on line the "Rediscovery of the Elements" DVD, published by Jim and Jenny Marshall in 2010. This DVD describes in minute detail all of the travels of Jim and Jenny during the period 1999–2008. Present plans are for Jim Marshall to prepare a 2nd edition of this DVD, to be put on line by the UNT Digital Library, by 2020.