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NOTES ON THE ELEVENTH INTERNATIONAL GEOLOGICAL CONGRESS HELD IN STOCKHOLM, AUGUST 18-25, 1910

By Horace V. Winchell, Dec. 6, 1910.

To this convention of geologists was accorded the patronage of His Majesty the King, Gustav V. The Honorary Presidency was held by His Highness Prince Royal Gustavus Adolphus, himself a scientist of repute, and a most accomplished linguist. His opening address, delivered in English to a polyglot audience, was as masterly, polished and in every way worthy a performance as if composed and presented by an American College President. The Executive Committee contained several members of the Swedish cabinet; and the Prime Minister also delivered an address, opening the discussion on the Iron Ore Resources of the World. The president of the Congress was Baron Gerard De Geer, Professor of Geology at the University of Stockholm, and a celebrated glacial geologist. The able and efficient secretary was Prof. J. G. Andersson, Director of the Geological Survey of Sweden. For nearly a year his entire time had been devoted to the task of providing the program and the entertainment for the large number of foreign members expected. The magnitude of such an undertaking may be partially comprehended when I tell you that there were about eight hundred enrolled and that more than two hundred and fifty took part in one or more of the excursions which began a month before the opening of the Congress and were still in progress for nearly a month after its close. The arrangements were complete to the last detail; and the executive ability of the Swedes compelled the admiration of every visitor to the Congress.

The membership of the convention was truly cosmopolitan, as may be seen by the following table of members enrolled before the day of opening:

Algeria	3
Germany	161
Argentine	2
Australia	2
Austro-Hungary	64
Brazil	1
Bulgaria	2
Canada	6
China	1
Denmark	22
Egypt	3
Spain	9
United States	63
France	53
Great Britain	44
India	1
Italy	30
Japan	6

Mexico	7
New Zealand	2
Holland	13
Portugal	4
Roumania	9
Russian Empire	56
Sweden	134
Switzerland	16

Among the notable geologists present were Richard Beck, author of the treatise on Ore Deposits; Alfred Bergeat, Dr. Groth, Max Krahmann, Paul Krusch, Dr. Lepsius, Penck, Stutzer, from Germany; Dr. Kremer, Carl Diener, Dr. Doelter, and Dr. Tietze, from Austria; F. D. Adams, A. P. Coleman, B. E. Fernow and W. G. Miller, from Canada; Dr. Steenstrup, from Denmark; Miss Bascom, Geo. F. Becker, Whitman Cross, Arthur Day, S. F. Emmons, Arnold Hague, C. R. Van Hise, W. H. Hobbs, J. D. Irving, J. F. Kemp, Waldemar Lindgren, D. H. Newland, H. F. Read, J. T. Singewald, J. W. Spencer, R. S. Tarr, E. T. Wherry, J. E. Wolff, F. E. Wright, Geo. Otis Smith, and others many of them accompanied by their wives, from the United States; Profs. Barrois, Margerie, Nicou and Oehlert, from France; Prof. Bowman, J. W. Gregory, Drs. Peach and Teall, of Great Britain; Dr. Fermor, of India; Capellini, B. Lotti, and others from Italy; Inouye, Director of the Japanese Geological Survey, and several other Japs; Aguilera and Ordonez from Mexico; Brögger, Reusch and Vogt, from Norway; Molengraaff, from Holland; Stefanescue, from Roumania; Karpinsky, Pavlow, Popoff, Revoutsky, and Tschernyschew, from Russia; Sederholm, from Finland; all the Swedish geologists, including Sven Hedin; Heim and Schmidt, from Switzerland; and many others of high reputation.

The excursions included ocean voyages to Spitzbergen in the Arctic Ocean, and the island of Gotland in the Baltic Sea. Other trips were made by special train from north to south in Sweden and Norway, furnishing a rare opportunity for seeing under the best possible auspices and chaperonage those localities where are exhibited the typical features and points of interest to students of structural, glacial and economic geology, and to the petrographer as well.

Thus at Spitzbergen were seen the magnificent glaciers on the margin of the sea, advancing, retreating or stationary. There were studied moraines of various types, the movement of complex glaciers, the deposits of glacial rivers and lakes, and all those various agencies now in operation, performing the same work as that by which was formerly deposited the glacial drift mantle over the state of Minnesota.

At Spitzbergen also is an excellent opportunity for the study of a mountain range folded and ruptured on the border of the Atlantic basin, and containing formations of different ages, from the Archean to the Quaternary. Here can be seen the origin of the fjords, those long narrow coastal inlets which make the coast of Norway, Scotland and British Columbia so picturesque and attractive to the tourist. The clothing appropriate for this excursion in July is that which we wear in Minnesota in November.

Excursions were also made before the Congress to the iron mines of northern Sweden; and another excursion after the Congress took us to the mines of central and southern Sweden. Others were made to Tornetrask, the alpine lake of the mountainous country in the north, and to the valley of the Luleälf, with its eruptive and metamorphic rocks, its glaciers and mountain climbing. Here the nights were spent in tents, and the days were full of laborious tramping.

In the vicinity of Stockholm excursions were made almost daily during the week of the meeting, always under the guidance of some star of the geological firmament, and always with the satisfaction of having seen with our own eyes phenomena of which heretofore we may have read and regarding the interpretation of which we were, perhaps, at heart somewhat skeptical.

And for each excursion and each locality there was a printed guide and description. For each day's work there was a plan. Almost was there a daily assignment for each individual guest. His comfort, conveyance, lodging, and three or more meals for each day had all been arranged beforehand.

The descriptive literature was today in German, tomorrow in French, and next day in English; and most of the Swedish gentlemen could converse or lecture in all three as well as in their own tongue. In fact, they sometimes caused a laugh by unconsciously lapsing from German or English into Swedish.

The Russians spoke French fluently and usually some English. The Germans spoke some French; the French a little German; and both of them could generally understand some English.

Besides our badges, we also wore ribbons; red, to show that we spoke German; white, for English; and blue, for French. Proud and fortunate, indeed, was he who sported all three. The English were the poorest linguists and most limited in their command of any tongue but their own.

Personally the Scandinavians are charming people, hospitable, generous, courteous, thoughtful, agreeable in conversation, cultivated and travelled. They are new and virile, without being raw and crude. Up-to-date in the adoption of modern inventions, ahead of us in some ways and in the van of modern progress in all. They are one of the most progressives nations in Europe today, and are more than holding their own in the march of development.

The museums of Stockholm are full of the most interesting and complete collections of human remains of the stone and bronze ages. Brief and measurable is the time that has elapsed since the Goths and Vandals were just stepping out of the bronze age; and here are their immediate descendants engaged in scientific studies and in all the activities of an ultra modern people! Think how interesting it would be if we could go out into the country only a few miles and discover the remains of our own great-great-great-grandfather's dwelling. If we could find in it the furniture and utensils which he and his family used, the ornaments they wore and the relics of the very food they ate. This is done in Sweden. They do not there find tumuli and say indifferently, "It was done by the Mound Builders." The ancient human relics are those which tell of the habits and civilization of their own people in the prehistoric times. They are, therefore, personally and intimately interested in such matters, and point proudly to the extent of their progress and development in a short time. And from this development they expect still greater things in the future.

The area of Sweden is 173,921 square miles; that of Norway 125,615 square miles. The two together are, therefore, somewhat larger than the state of Texas. The population of Sweden is about 5,150,000, and of Norway 2,250,000. Together the two countries have a population about equal to that of the city of London. There are only five cities in Sweden with a population of more than 30,000: Stockholm, Göteborg, Malmö, Norrköping and Gefle.

Half of its population is supported by agriculture; and about one-quarter own their own farms. The crops are varied, consisting largely of grain, hay, sugar beets, hemp, flax, potatoes and small fruits.

The exports from Sweden amount to more than $100,000,000 annually, of which over half goes to Great Britain. The products exported are timber, iron, butter and wood pulp.

Forests are abundant and well cared for. South of latitude 64° N. one-fourth of the entire land is forested. In southern Sweden and Norway, as well as in Denmark, are venerable forests of solid oak and beech. Much charcoal is made for use in iron ore smelting.

Lakes and rivers are numerous. The more important streams flowing into the Baltic are the Tornea, Lulea, Pitea, Skelleftea, Windel, Umea, Angermann and Dal. Into the German ocean flow the Klar and Gota. The largest body of fresh water, lake Wener, has an area of about two thousand square miles.

Much of the southern half of Sweden is lowland. Toward the north the country is more elevated, and a range of mountains lies on the border between Sweden and Norway. The highest mountain, Kebnekaisse, in Swedish Lapland, rises to the height of only about seven thousand feet.

The climate is good. Winters are long, and the summers hot. There is but little Spring and Autumn. The influence of the Gulf Stream is marked; and the western coast of Norway, at the same latitude as our ice-bound Bering Sea, is as mild as our climate at New York or Boston.

Nearly all of the interesting features of Sweden's geology were described in the forty little monographs prepared by the Swedish geologists and published in convenient form for our use at the Congress and upon the various excursions.

There is time this evening for only a brief abstract of a few of the most important and interesting of these papers.

For the glacial geologist there was an illustrated lecture and article upon the "Quaternary Sea Bottoms of Western Sweden" and an account of "Some Stationary Ice Borders of the Last Glaciation" by Baron Gerard De Geer. In the first of these articles it is pointed out that the land ice was possessed of but feeble power of glaciation, and that instead of eroding deep gorges and valleys and planing off hundreds or thousands of feet of solid rock, its direction of flow was determined by the valleys coincident in strike with Tertiary rock fractures and dikes; and the work of the ice was limited to the sweeping out of the crushed material to the extension and depth predestined by the pre-Quaternary act of crushing. The ice sheet's power of glaciation, working during the whole length of the ice age, is said to have been unable to obliterate or essentially change the surface topography; and only put its stamp upon the landscape by grinding off the proximal ends of the rock edges to the well-known ice-worn "round-rocks."

The origin of giant-kettles or pot holes is explained through the characteristic corrosion by sub-glacial rivers where such currents pushed forward by a strong hydrostatic pressure passed over rock ledges so as to form sub-glacial whirls. The assumption frequently made that these kettles were formed by water falling down through crevasses is found untenable, at least when applied to the many low-lying kettles, which at the time of their formation, were situated at a considerable depth, even as much as three hundred and twenty-five to five hundred feet below the surface of the sea. In such cases even the crevasses must evidently have been filled to at least the same height by standing water, and it does not seem likely that a water fall could bore out holes in the bed rock through such a depth of standing water. The extraordinarily strong rapids of the sub-glacial rivers were no doubt more than sufficient to produce even giant's kettles of such imposing dimensions as those sometimes found in Bohnslän, some ten to twenty feet in diameter.

The late glacial recession of the ice proceeded at a much greater speed on the continental than on the oceanic side of Sweden. Thus the recession of the ice border through Bohnslän and the adjoining part of the province of Dalsland took the same amount of time as the whole recession from the south end of Sweden up almost to the Aland archipelago, i. e., over three thousand years.

By means of the deposits of fine glacial clay carried by sub-glacial rivers out into the advancing ocean as the ice retreated, it is ascertained that the late glacial sea covered a large part of Denmark and extended to central Sweden and Norway, and that there were important changes of land and sea level, amounting to hundreds of feet. There were for example great shell deposits of shallow water forms laid down where the water had been previously more than three hundred and twenty-five feet deep.

A careful study of the layers of clay and sand deposited in the late glacial sea has furnished a most accurate measure of the chronology of the retreat of the ice sheet. Baron De Geer points out that, while there were many variations in the rate of recession of the ice margin, the average rate of retreat in the vicinity of Stockholm was two hundred meters per year. South of Stockholm for some distance the rate was from twenty to one hundred meters per annum. At some points to the north, notably near Dal's Ed near lakes Venern and Vettern, the ice border remained stationary for one hundred or two hundred years.

Baron De Geer's estimate of the lapse of time since the retreat of the ice at Stockholm is about seven thousand years. Farther north the ice lasted until a much later period; and the northern part of Sweden was probably covered with ice only two thousand years ago.

It may be remarked in passing that this estimate compares well with that made first in the gorge of the Mississippi river by Prof. N. H. Winchell, as well as with the later similar measurements by Gilbert and Spencer at Niagara Falls.

For the student of the Archean there is a splendid field in Sweden. The rocks are fresh, glaciated and exposed to view on sea coast, along the new river courses and on the mountain sides. Everywhere the landscape reminds one of Minnesota and Ontario, and, like Minnesota, Sweden has many great iron mines. In fact, there is found a greater variety of workable ore deposits than has thus far been discovered in our Archean territory. To the economic geologist, Sweden is one of the most interesting countries on the face of the round globe. Its great age as a center of mining, the magnitude of its deposits and their unusual types provide material for innumerable "kolossals" and "wunderbars" of the Teuton and challenge the utmost exaggeration of the Yankee to suggest their equal in his own land. Historically, mining operations here are lost in the mists of antiquity. Methods and machinery had established vogues and patterns three hundred and fifty years ago in the days when Agricola, the Nestor of mining, published his classic treatise. Indeed, some of the machinery pictured by him in 1556 still finds its counterpart in Swedish iron and copper mines, steadily doing duty side by side with electric hoists or smelting plants of the most up-to-date design.

Although paleozoic and mesozoic strata are found in Sweden, yet the larger portion is covered by the Archean rocks, gneisses, schists and intruded rhyolite and porphyries. These eruptives have been in many instances profoundly altered, and the ancient ore deposits, which they were instrumental in producing, have undergone a varied and unusual history.

The Swedish Archean consists of three petrographically and geologically different groups of rocks. These have long been named: The gneiss-group, the porhpyry-hälleflintgneiss group, and the granite group. Recently an alteration was made in this terminology by the exchange of the term "hälleflintgneiss" for leptite, the latter having been proposed already in 1875 as a collective name for the same rocks.

The porphyry-leptite group, as the new designation also runs, includes fine-grained gneisses, schists of many types, also green schists, dense rocks, called in Sweden a long time ago "hälleflinta," limestones, dolomite and argillaceous schists, quartzite and conglomerates together with porphyries and porphyroid rocks to a large extent. Many of the rocks of this group bear evident traces of having once been formed as real surface-products of the earth: lavas, tuffs, tuffites or normal sediments, the latter, however, being only subordinately represented in the Archean. The leptites themselves, which form by far the greatest part of this group, are closely related to the other rocks and seem to be metamorphosed rocks of volcanic origin: lavas, tuffs or tuffites. Consequently the "porphyry-leptite group" corresponds very well to the designation supercrustal rocks, which has newly been proposed by the eminent explorer of the Fennoscandian Archean, Dr. J. J. Sederholm.

Supercrustal rocks also form a great part of the gneiss group, but the high-grade of metamorphism which designates the gneisses, mostly conceals their primary petrographic character and geological relations so as to make their origin in many cases doubtful. The gneiss group includes also gneiss-granites. By this term Swedish petrographers understand granites of strongly regional metamorphic character, i. e. crushed, foliated or granulated granites, often with a clearly marked secondary parallel structure.

The third group is the granite group. This embraces all the numerous types of granites, in which the Swedish Archean is so very rich. Great areas of Sweden consist of these rocks. Together with the gneiss-granites they certainly make up much more than 50 per cent. of the whole Archean system. The contacts show that the granite-magmas have cut all the other rocks and they must, therefore, be considered younger than these rocks. Their properties are those of real plutonic eruptives. Together with the said gneiss-granites and the gabbros and diorites, which appear in smaller quantities, the granites may be said to form the infracrustal rocks of the Archean, in accordance with the nomenclature of Sederholm.

In the coast-regions, east and south of Stockholm, gneissose rocks predominate; yet the granites and the porphyry-leptite-group are also very well represented.

Of the gneisses there are found both supercrustal and infracrustal types. The origin of some gneisses cannot yet, however, be stated with certainty.

What is known as the porphyry leptite group of rocks is associated with iron ores in central Sweden and also in the coast regions near Stockholm, extending along the coast to the islands Utö, Ornö, Namdö and Runmarö. The rocks are hälleflintas, leptites, mica schists, porphyry, epidote-or amphibole-bearing green schists, calcareous schists, limestones and iron ores. They are all bedded, often regularly and with alternations which make them closely resemble stratigraphical complexes. Their structures are, however, wholly crystalline and the bedding planes are now always nearly vertical.

The iron ore at Utö is the type known as "randig blodsten," i. e. quartz-banded hematite similar to our jaspilite. The quartz is gray or reddish, and the iron ore is hematite with more or less magnetite. Beds of amphibolitic rocks accompany the ore and thin green layers alternate with the iron ore strata. The mines at Utö were worked as early as the beginning of the 17th century, and operations continued down to 1879. From 1711-1878 the output was 2,070,900 tons of iron ore. The total production is estimated at 2,500,000 tons. The ore was not high grade, containing before concentration but little over 40% of iron. The Nyköping mine was worked to a depth of about 650 feet, and the Finn mine about 500 feet.

Two famous lithia pegmatite dikes cut across the folded iron ore body of Nyköping. Here the element lithium was first detected by Arvedson, a pupil of Berzelius, in 1818. These dikes are among the most importanc known natural resources of lithia. The dikes consist mainly of petalite, quartz, lepidolite and coarse green orthoclase. They also contain spodumene, blue and red tourmaline (indigolite and rubellite), microlite (a tantalate of lime), mangantantalite and adelfolite. One of the most amusing sights of the tour was to see the Germans with hammers of all sizes up to that which tradition ascribes to the War God Thor, descend upon a mineral locality. No classic exposure was sacred. The best is none too good for an unmodified Teuton, and the baggage car attached to each special train was so loaded with rocks that hot boxes were numerous. For pure unadulterated selfishness the average German has not an equal in northern Europe, and his manners would shock an Eskimo.

Adjacent to the iron-bearing hälleflinta zone of Utö is a mighty series of limestone and hälleflinta. The limestone is finely crystalline and alternates with the hälleflinta in bands from only a few centimeters to several meters in thickness. Where intensely folded and crystallized the hälleflintas resemble amphibole schists; and, indeed, the bedded complex is bordered on the east by a thick layer of green amphibolitic rock containing thin limestone layers. This green rock resembles the green skarn or gangue rock of the iron mines farther north.

Associated with these rocks is a greenish gray bedded leptitic hälleflinta which likewise contains a few thin beds of limestone. Then comes the regular bedded leptite, containing layers of nearly massive porphyritic rocks, which are undoubtedly altered lava beds and tuffs. The leptite is cometimes quartzitic and almost itself a quartzite. It is composed of quartz, feldspars, biotite and muscovite.

There were silver mines also at Utö. Native silver occurs mingled with epigenetic sulphides of copper, iron, lead and zinc. The mines are not now operated and were never important.

The hälleflinta here is looked upon as a volcanic mud. It is a quartz feldspar sediment, mingled with volcanic ash and sedimentary limestone. It is even occasionally coal-bearing. The iron ore is regarded as a chemical sediment.

Passing from the coastal region to the central portion of Sweden, we come to the university town of Upsala. If Stockholm is the Venice of the North, Upsala is surely the Boston of the Arctic. Here for hundreds of years has been a center of learning and culture. Here lived and wrote Sweden's greatest scientist, Carl von Linnaeus; and his house, with all of his natural history collections, is still preserved on the old farm, a couple of miles outside of the city. The main university building is a fine structure, on an eminence, surrounded by statues of some of its celebrities and containing oil portraits of many others. Near it is the Upsala Lutheran Cathedral, which is one of the notable structures of the country.

Not far from Upsala are Dannemora, Sala, Krylbo, Karrgrüfvan, Norberg, Hagge, Ludvika, Grängesberg, Persberg, Ammeberg and Falun.

Like many other Swedish iron mines, Dannemora was first worked for precious metals. The date of its discovery is approximately fixed by a deed of gift dated 1481 by which Sten Sture, the Elder, conveys to the Archbishop of Upsala and his successors one-fourth of the silver mountain in the parish "which was discoverd a a few years" before.

When Gustav Vasa secularized the church lands, the mine reverted to the crown, and was first leased to Joachim Piper, a burgher of Stralsund in 1532. Iron ore was still only a subordinate product mentioned along with "sulphur, vitriol, antimony, lead, tin, copper, silver and gold." By 1545 iron ore production had become important, under a lease from the crown. Later, in the 17th century, the works and mines passed into the possession of private owners.

Gunpowder for breaking the ore was first tried at Dannemora in 1728; and in 1727 a wonderful "fire and air engine" was set up for raising the water. In 1805 a steam engine of Watt's construction, the first in Sweden, was installed.

The rocks at Dannemora are crystalline schists with intrusive granites. There are also other intrusive dikes. The Dannemora ore district is chiefly occupied by hälleflinta, and the porphyritic hälleflinta has the greatest extent. It almost encloses the limestone and other varieties or phases of the hälleflinta. This so-called porphyritic hälleflinta consists of a dark colored microcrystalline fine grained quartz feldspar rock with a rich admixture of a sericitic mineral of secondary origin. Chemically, it is an acid quartz porphyry. Many varieties in color, texture and geological relations occur in this field; and north of lake Grufsjön it passes into granulite or leptite.

The ores are enclosed in a limestone mass, which is in turn surrounded by the hälleflinta. This limestone has a length of about three thousand meters and a minimum width of about four hundred and fifty meters. Composed exclusively of magnetite, the ore has a characteristically fine-grained structure, often as compact as steel. It occurs associated with skarn or gangue (called "bräcka") and more or less mingled with limestone. The percentage of iron varies from 20% to 65%.

The more important ore deposits belong to a number of complexes, some of which contain several parallel ore layers. In each complex there occur several independent ore-stocks, separated by limestone or "präcka." Such ore stocks may be connected with other ore stocks in the direction of the pitch or toward the depth. They are usually nearly vertical. Their horizontal extension in the line of strike may reach two hundred to three hundred meters and their thickness thirty to forty meters.

The mines of the central field have been opened from the surface on several ore-bodies of great thickness, partly separated by gangues and branching toward the north. On the south this extensive ore-formation is almost entirely cut off by a system of parallel chlorite leaders, which form the southern wall of the Hjulvind mine, and somewhat resemble a fault. These chlorite bands or sköls were probably originally diorite dikes which acted as a dam in cuttting off the ore injection or the solutions by which it was formed.

Quantities of sulphides, chiefly zinc blende, have been introduced metasomatically at a later period, impregnating both the ore and the later granite intrusions.

The mines of Langban have produced small amounts of argentiferous galena and sphalerite and considerable quantities of manganese and iron ores. Here, as elsewhere in central Sweden, the ore-bearing formation is the crystalline schists. They are here chief-dolomite, which is characteristically banded by lime magnesia silicates, except adjacent to the ore and sköl.

The ores occur in stockworks, usually containing both iron and manganese. There appears to be a tendency to scatter and diminish in importance at moderate depth. The gangue of the iron ore shoots is called "skarn" and is of varied color and mineral composition, containing gray-green malacolite, brown and black garnets and ferruginous quartz. There are also unimportant deposits of sulphide ores of copper, iron, lead and zinc. Many sköl layers or bands bound the ore and extend thro the adjacent rocks. In some instances these sköls are squeezed and altered greenstone dikes that seem to have been present before the ore was deposited, and to ly granulite and dolomite. Closely associated is a gneissic granite. Two varieties of younger intrusive granite dikes occur, and various still later diorite and diabase dikes. Pure dolomite bears such a constant relation to the ore or sköl formations that it is concluded that the ore-depositing agencies had a marked effect also upon the have formed a boundary to it or determined its extent. In other cases the sköls are more or less micaceous and represent transformed granulite or leptite. Still other occurrences resemble very old shear zones or fault planes whose filling has been transformed into crystalline rock material. Still later fracturing has occurred, and the cracks have been filled with calcite and other secondary minerals.

In this same neighborhood are also the mines of Norberg, Flogberget and Persberg. The principal features of interest are the "skarn" ores and the calcareous ores, the former of which are hornblendic magnetites and the latter serpentinous and amphiboliferous limestones intermingled with small patches and lenses of skarn ore.

Persberg is one of the oldest mining fields in Vermlands Bergslag. Mining dates back to the 13th century; and the first mining privileges were granted by King Eric the Pomeranian in 1413. The Bergmaster's report for 1637 states that "the whole mountain is nothing but ore, and of mighty richness, and can be smelted without flux," from which it can be seen that the art of writing mining prospectuses based largely upon the imagination did not originate in the United States. The total output of the Persberg mines is estimated at less than 4,000,000 tons. Fifty years ago the annual production was about 50,000 tons. At the present time it is about 30,000 tons. The ore is of excellent quality and has contributed largely to the reputation of Swedish iron in the world's market. The best grade of ore contains 55½ Fe, 0.001—0.004% P; and the second grade 45% Fe and 0.005—0.01% P. The sulphur content varies from 0.012 to 0.025%. The deepest workings are now about 1,000 feet. Machine drilling was first started in Sweden at Persberg in 1864-1866. These mines were well described by Linnaeus about 1746. Powder for blasting was introduced about 1720.

The skarn ores are believed by Sjögren to owe their origin to the metamorphic influence of greenstones upon limestones. There are, however, considerable ore-deposits which are, so far as can be seen, without any immediate limestone association. The granite eruptives may also in some instances have been active mineralizing agents. Granulite or leptite is abundant, cut by skarn zones, which contain the ores.

The history of the Sala lead and silver mine extends over four centuries. The ore deposits seem to have been discovered early in the 16th century, being mentioned in a document dated September 1, 1510. Its palmy days were in the early half of the 16th century, when it furnished an important part of the public revenue. By 1571 mining operations were difficult on account of water. Kings Carl IX. and Gustavus Adolphus both tried their hands at it; but for fifty years only little progress was made. The grade of the ore declined with greater depth, and renewed exploration in the upper levels discovered more ore once in the latter part of the 17th century and again a hundred years later. It is stated that the mine was worked at a loss during the whole of the 19th century. At present an effort is being made to utilize the zinc ores that were left in the mine by former operators.

The total production of silver of the Sala mine is estimated at about 400 tons, of which about one-half was produced in the 16th century. Sjögren states that from an economic point of view the mine was run at a loss for three centuries. It was kept going only by means of special privileges from the Crown.

We find here again the crystalline schists or basal complex of hälleflinta and limestone, cut by granite and porphyrite intrusions and by later diabase dikes. The carbonate rocks are most closely connected with the ores. The galena is found chiefly in the limestones and only to a very subordinate extent in the hälleflinta. Copper ores also occur in the limestone; while small iron mines in the district are connected with the hälleflinta.

This latter rock here presents an extremely varied formation whose only common character is the felsitic texture of the groundmass. It is dark, or light gray or brownish, and is sometimes striped or banded. A few varieties have a purely granitic or quartz-porphyric constitution; in general, however, the percentages of alkali are lower than in the quartz and felsitic porphyrites, and the constitution corresponds rather to that of the dacites and quartz-porphyries, with which rocks the hälleflinta also shows points of agreement in the quantity of Fe—Mg silicates. On the whole, the rock in its composition stands closest to the intermediate eruptives. The percentage of lime, which preponderates over that of Mg, and the often considerable percentage of Na, which often outweighs the K, forbids the interpretation of it as a metamorphosed sedimentary rock. It grades into the dolomite limestone both by an increased percentage of the calcareous material and by close interbanding.

The fact was noted at an early date that the ores declined in richness toward the deep. This phenomenon, which is not peculiar to Sweden, is commonly ascribed to secondary enrichment from the surface downward; but Prof. Sjögren, to whom we are indebted for a description of many of these mines, and who went with us as guide, philosopher and friend, does not accept that theory here.

Before leaving central Sweden mention should be made of the Grängesberg iron ores. They occur in the usual formation of gneissic rocks, called granulites or hälleflinta gneisses or leptites. Included in this formation are also amphibolitic or dioritic greenstones, skarn rocks, crystalline limestones and iron ores. Later granitic and diabasic eruptives are also present.

The ores are (a) apatitic; (b) quartzose hematites; (c) skarn ores, and (d) calcareous ores; the latter two as well as the first being non-manganiferous, non-titaniferous magnetites. The iron content varies from 55% to 65%; and the phosphorus from 0.1% to 8%. Thus the mineral apatite sometimes amounts to more than 40% of the ore.

The low grade magnetite ores of central Sweden are now being concentrated on a considerable scale. The process most favored in that country is called the Gröndal process from its inventor.

The raw ore containing from 27% to 55% iron is broken in a crusher, and ground to sand in a ball mill. The magnetite sand or concentrate, containing 67% to 71% iron, is taken out by magnetic separation, moistened and moulded into bricks about 6 inches square and 2½ inches thick. No binder is used. The bricks are simply pressed and moved slowly on iron conveyors through a furnace heated with generator and furnace gases and subjected to an oxidizing flame at the temperature of about 1400° C., which is above the sintering heat. In these furnaces the magnetite is changed to hematite, the percentage of sulphur is lowered, and a hard porous briquet is made very suitable for the blast furnace. By this process, at a cost of about eighty cents per ton, some twenty-seven Gröndal furnaces are turning out about 300,000 tons of briquets per annum. Since magnetite briquets require about 300 pounds of charcoal per ton of pig iron more than those made of hematite, the expense of the briquetting is justified in a region of sulphurous magnetite ores. This process is of special interest in Minnesota because of the large quantity of low grade magnetite ores on the eastern end of the Mesabi range, at present unmarketable.

There remains for description in central Sweden what is historically one of the most remarkable mines in the world, viz: the Falun copper mine. Worked without interruption for the past six hundred and fifty years, it had down to the end of the 19th century produced more copper than any other mine on the globe. From 1630 complete records of its production are extant, according to which the total output in that time amounts to nearly 300,000 tons, or 600,000,000 pounds of copper. From the commencement of mining operations to the present time its output has been estimated at 500,000 tons of copper, one ton of gold and fifteen tons of silver, having an aggregate value of $250,000,000. For the sake of comparison we may note that in these days of monumental performances the total estimated copper output of the Falun mine in six hundred and fifty years is about equal to three years' production of the mines of Butte.

The ore was formerly richer than in later years, and the possibility of secondary enrichment is again suggested. At present the mine is worked for pyrite, which is used in the sulphite pulp digesters belonging to the company which operates the mine.

This corporation, by the way, although one of the oldest in existence, is one of the most progressive and profitable concerns in Swdeen. The date of its actual foundation is not known; but it is supposed to be about the year 1225. There is in existence a deed dated 1288 conveying certain shares of stock; and one charter of the company, given by King Magnus of Sweden and Norway, is dated February 24, 1347, and at that time ratifying and confirming the company's rights and privileges which are mentioned as very old.

The company, whose full address is Stora Kopperbergs Bergslags Aktiebolag, Falun, Sweden, began to make or produce

Copper about the year		1225
Sawn lumber in the year		1689
Iron		1735
Gold and silver		1790
Steel	Bessemer	1871
	Open hearth	1878
	Electric	1904
Pulp	Soda (sulphate)	1895
	Sulphite	1900
Paper		1900
Bismuth		1904

It owns vast forests, two hundred iron mines, and water-falls estimated at 150,000 horse power. It makes the specially soft charcoal wrought iron for which Sweden is famous. Its annual production is

75,000-100,000 tons pig iron.
70,000 tons Bessemer ingots.
26,000 tons open hearth ingots.
4,000 tons charcoal iron blooms.
75,000-100,000 tons rolled and hammered iron and steel.

It uses 450,000 cubic meters of charcoal per annum, making 150,000 cubic meters in its own kilns.

The Falun mine, called "The Country's Treasury" by Gustavus Adolphus, is 1200 feet deep and has about 18 miles of underground workings. The bottom of the mine is now full of water, and many of the old workings are inaccessible. During the first 400 years of its history the ore was broken by burning wood against it. Gunpowder was first used in 1729. The ore was raised by means of windlasses worked by hand or horse power, and the ropes were made of ox-hides, 200 to 300 hides being required for a single rope.

The country rock at Falun is the crystalline series in the form of gray gneiss and granulite or leptite. The gneiss is locally a quartzite which is the true ore-bearing rock, and to it belong also the other copper ores of this and adjacent districts. It contains as accessory minerals amphibole, cordierite and its alteration products, falunite, andalusite and magnetite. There is also considerable white saccharoidal limestone. Composite basic dikes also occur, cutting both ore and country rock.

The ore of the Falun mine is pyrite of various modes of occurrence, and more or less associated with sulphides of lead and zinc. In the upper levels the ore was considerably enriched, and probably contained the higher grade copper sulphides. Occurring in stocks of bluntly conical form with the point downward the interior structure of the ore bodies cannot now be studied. They consisted largely of nearly pure pyrite with a slight percentage of copper. There was also a quartzose mixture of copper pyrite and pyrite containing angular fragments of quartzite and limestone.

There is here also a considerable development of skarn at the contact of quartzite and granulite. It consists of a dark green mass of radiate amphibole sometimes garnetiferous. Then there are sköls more or less closely connected with the pyrite stocks and surrounding them or separating them from the other rocks. The sköls consist partly of primary minerals, such as amphibole, biotite and cordierite and partly of their hydrated derivatives, chlorite, talc and falunite. There are also secondary garnets and magnetite octahedrons and later sulphides. The sköls sometimes have a thickness of ten to fifteen meters, and again they thin out rapidly. They grow smaller in depth and have in general a development proportional to the extent of the ore mineralization. The richest ores the mine ever produced came from the upper zones of the sköls.

The "hard ores," so-called, lie immediately in the quartzite without being enclosed by sköls or leaders, and pass by insensible gradations into the rock itself. All the ores appear to come to an end at the maximum depth of 250 to 280 meters.

Gold occurs associated with galenobismuthite, in small quartz veinlets. Some selenium has also been found associated with trap dikes which contain amphibole in a felsitic ground mass of quartz and plagioclase. The gold ore was richest at the depth of from 40 to 100 meters. Workable gold ores have not been found below 200 meters.

The surface of the pyrite and neighboring limestone in some places retains the grooving and striations of the glacial period. It is interesting to note that there has been barely perceptible oxidation and solution in the five thousand or more years that have elapsed since Jack Frost here made his mark.

One of the memorable events of the trip was a luncheon held deep underground in an old stope in the Falun mine. Lighted by a thousand candles, and with a blazing fire in an old rise connected with the surface, the table spreads dazzled us by their whiteness against the dark rock background, and the glasses and silverware sparkled with unusual brilliancy. Here in this immense chamber had worked miners before the discovery of America. The marks of their tools remain, and the place where the last pile of burning faggots hollowed out the solid ore, or the face of the drift smooth and rounded instead of rough and jagged as when made by explosives, conveys a faint idea of the infinite slowness and labor with which the work of mining was carried on. Here on the rocks are carved the names of rulers and nobles long since passed away. Even the room itself bears the name of "Algemeine Frieden", or Universal Peace, given to it at a celebration after the battle of Waterloo.

After luncheon speeches were in order and then a German mining song led by Graessner and sung to the finish with increasing gusto and effect. Our way to the surface and daylight was up the easy steps cut in the rock, where climbed the miner in the days of the Reformation, and where even before that time sat Roman foreman with old-style candles, counting the men as they passed. It was all impressive and made us feel small and new and insignificant.

From the oldest and most important copper mine in Sweden we passed in two days' travel almost straight north to the youngest iron mine in Sweden and the largest in the world. This mine is in Swedish Lapland, and is called Kirunavaara or Ptarmigan mountain. It has been opened and put in operation during the past ten years under the management of a Swedish Captain of Industry named Hjalmar Lundbohm.

Here within the Arctic circle, North latitude 66°, where the electric lights are started at 2:30 on winter afternoons, are twelve hundred men mining iron ore for shipment to England, Germany and the United States. The daily output is about 9,000 tons; and it is shipped over a first-class modern railroad in steel ore cars about one hundred miles farther north to the harbor of Narvik on the Norwegian coast, already mentioned.

The amount of ore in the Kirunavaara has been repeatedly estimated; and each time the estimate is larger. When it is realized that this deposit of hard ore averages about 275 feet in thickness and is more than two miles in length, and rises in a mountain about eight hundred feet above the surrounding country, it may not be so difficult to believe that it contains approximately one billion tons of ore.

It is mined in open cuts or terraces; and the blasting can be heard for fifty miles. The annual output of ore now amounts to about three million tons. It is limited by the Government at present to 3,500,000 tons. The Swedish Government not only owns one-half of the stock of the operating company, but has an option to purchase the remaining half at an agreed price in about twenty-three years' time.

There is material for an evening's lecture in this mine alone, and there is only time now for a brief mention of it and its salient features. Although attention had been repeatedly called to this mountain of iron by Laplanders and hunters returning from the far-away northern wilds, yet very little was known about it until the Swedish Geological Survey Party led by Dr. Lundbohm camped there and collected material for reports. The first time was in 1875 and the second in 1896. Situated about 145 kilometers north of the Arctic Circle, 300 kilometers from Lulea on the Baltic, and 170 kilometers from Narvik, the distance from Stockholm is 1413 kilometers, or about 850 miles.

The first work preparatory for mining was in 1898. In 1899 the railroad (owned by the Government) reached Kiruna, and in 1902 was built to Narvik. Shipments began in 1903 with a production of about 800,000 tons.

Kiruna is situated in a desolate country, uninhabited before mining began, and only periodically visited by the nomadic Laps, for hundreds of years the only dwellers in the district. The climate is severe, the yearly average temperature being about 37° Fah. Winter lasts from the first of October to the end of May, and the snowfall is heavy. Kiruna is now a well-built town of about 7800 inhabitants. An elctric railway carries the miners to the foot of the mountain, and covered tramways or inclines take them up to the working faces. Hitherto the work of quarrying the ore has not been attended by any unusual problems, but as depth increases and the amount of rock to be mined becomes more nearly equal to the tonnage of ore, there will be an opportunity for the display of engineering skill of a high order. The average dip of the ore is about 55° to the east, and the foot wall rock as well as the hanging is already being mined in considerable quantity.

The ore is massive and dry, and the rocks above and beneath are likewise solid and fresh crystalline rock. Hence, the ground stands well and only an occasional pillar is needed even in large excavations.

The grade of the ore is high. Indeed, the Swedish ores constitute one of the most important sources of high-grade iron ore in sight today. The chief impurity is phosphorus in the form of apatite. This, however is so plentiful that instead of being detrimental it becomes an important asset. By the use of the Thomas-Gilchrist process the phosphorus is saved and converted into phosphoric fertilizer. Indeed, the Germans pay about as much for a unit of phosphorus as for a unit of iron. In this respect again we would do well to take a lesson from European practice. There is no one material resource at once so valuable and necessary and so scarce as phosphorus. I am inclined to the opinion that our phosphate products should all be by law retained within our own borders; and that we should avail ourselves of the opportunity to buy and utilize more of these Swedish high phospnorus ores. At present our seaboard iron furnaces import from Kiruna a certain grade of low-phosphorus, high-in-iron ores. The ore thus far produced from this Arctic Circle mine has averaged as follows :

Grade A	1,141,302	tons	Average	69.63	Fe	0.024	Phos
B	67,387	"	"	69.25	"	0.67	"
C	371,854	"	"	68.60	"	0.162	"
D	7,003,158	"	"	62.48	"	1.88	"
F	278,966	"	"	59.34	"	2.78	"
G	708,636	"	"	57.77	"	3.09	"

The amount of titanic acid in the ores is generally less than 0.5%; and the sulphur averages 0.05 or less.

But little is known concerning the geological age of the Kiruna ore and the surrounding sedimentary and igneous rocks. They are presumed to be pre-cambrian and post-archean. The geology of the ore deposits is complex and most interesting, and has been made the subject of careful study by Lundbohm and Geijer.

It is a remarkable fact that the great ore bodies of Kirunavaara and Luossavaara, (which lies a mile or two farther north, almost in line of strike), occur between two beds of porphyries of rather similar composition. The foot wall consists of syenitic rocks with a silica percentage of about 60, the hanging wall of quartz porphyries with about 70% silica.

The quartz porphyry is interwoven with innumerable dikes of finely crystalline apatite, generally small, but sometimes more than one meter in thickness. These dikes are often rich in magnetite and hematite. They also often contain much tourmaline and sometimes quartz and albite and show flow structures and orientated intergrowths. The quartz porphyry on the eastern side of the ore also contains numerous fragments of magnetite similar to that of the iron mountains. No dikes of magnetite are found cutting the quartz porphyry; but many intersect the syenite on the west. The contact between ore and country rock is generally sharp and distinct. The ore consists chiefly of magnetite; but contains hematite in small irregular lumps, in isolated crystals and in small veinlets. The ore is sometimes laminated and intimately banded with alternating layers of apatite. Some geologists have mistaken this structure for evidences of sedimentary origin.

According to the two main theories, this ore is either pneumatolytic-hydrothermal or magmatic. It occurs in a series of bedded eruptives; is younger than the underlying syenite porphyry and older than the overlying quartz porphyry. It was, therefore, formed either by gaseous emanations from the older rocks during an interval or pause in the outpouring of solid eruptive matter or is an actual eruptive sheet or dike of magnetite from an acid magma. In either case it is a deposit of rare type and phenomenal importance.

Near the southern border of Lapland is still one more important iron ore district. This is at Gellivare. Iron ore was mined here in the 18th century, being transported by reindeer to small blast furnaces in the vicinity. It was only the invention of the Thomas-Gilchrist process which finally created a demand for these high phosphorus ores. The production is now about 1,200,000 tons annually. The production to date is about sixteen million tons; and the total estimated tonnage about 270,000,000. The ore is shipped during the summer to Luleå and goes chiefly to Westphalia and to Silesia; some of it also goes to England and America. The Swedish Government is a partner in the enterprise and the output is limited to about the present amount.

The geology is even more difficult than at Kiruna, because the rocks are more metamorphosed. It is apparent, however, that they were syenites and syenite porphyries originally, now recrystallized and granulitic or gneissoid. Apatite and titanite are abundant and there is plenty of quartz. Sillimanite and corundum are also present. There are dikes of metabasites, granites and pegmatites. The granite and pegmatite dikes frequently intersect the ore masses. Skarn breccias are also numerous, presenting in many instances striking structural and mineralogical similarities to the skarns of central Sweden.

The magnetic ore varies from 62% to 69% in iron and from 0.013 to 5% in phosphorus. Structurally the ore is hard and granular; and there is a parallel banding or striping due to the arrangement of the apatite.

The main ore belt has a length of about two and a half miles.

The ore is in irregularly shaped lenses or bodies, rising above the general level and even above timber line at this northern latitude.

Mining methods are modern and economical; and the adaptability and progress of the Swedish people everywhere evident is nowhere more strikingly exhibited.

An illustration of their keen interest in the subject of natural resources and iron ores in particular is afforded by the monumental work upon the iron ore resources of the world prepared by the Swedish members of the International Geological Congress and published in Stockholm in time for this meeting. This series of monographs in two quarto volumes with an atlas volume, represents the world's combined knowledge of the extent of the iron ores of all countries. Written largely in the English language, but also partly in German and French, it is the most elaborate statement of the subject ever heretofore prepared. It is not the work of one man, but of specialists in many parts of the world, all contributing their best data for enlarging the information of the people of the world upon a subject of vital importance. Although there is not sufficient time for me to review this publication, attention should be called to it as one of the most valuable of the products of the Congress.

Many other mines and localities interesting geologically have not been mentioned. An evening could be devoted to a description of the government method of owning and operating railroads in Sweden. Another lecture could be given upon the subject of water and electric power development and the progress and hope for the futur in the electrical metallurgy of iron and steel. Still other discourses could be devoted to the scenery, to the customs and costumes of the people, to their native industries and their accomplishments in music, painting, sculpture and literature. And after presenting a picture or description of all these, and more, there would still be so much untold that it would be necessary for you to go and see for yourselves,—and this I can in all sincerity recommend,—for, surely, nowhere within the bounds of civilization can be found warmer hospitality, truer friendship or gentler courtesy than among our flaxen-haired cousins of the far North, the Swedes.