XIII. *On the Age and Origin of the Metallic Veins of the Upper Harz.**

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Contents.—1. Topography; 2. Geology of the Harz Mountains; 3. Faults of the Upper Harz; 4. The Clausthal Veins; 5. St. Andreasberg Veins; 6 Suggested Origin of Veins.

1. The Harz Mountains rise from the great plain of secondary and tertiary formations in the western part of Prussia, about 130 miles inland from the seaboard at the mouth of the Elbe. Like the Thüringer Wald and other adjoining ranges, the Harz trends in an approximately east-south-east and west-north-west direction, and resembles on the map an elongated ellipse with a northern flattened side some 50 miles in length. It has been compared to a single mountain with large shoulders, culminating in the celebrated Brocken, 3,746 ft. in height. A line drawn through the Brocken from north to south roughly divides the region into two parts. The eastern division, drained by the Elbe, is rather flat and featureless. It has an average height of 1,600 ft., and is locally known as the Lower Harz (Unterharz). The Western or Upper Harz (Oberharz), drained by the tributaries of the Weser, rises to a height of about 2,000 ft., and is the seat of the great lead and copper mines for which the Harz Mountains have been for many centuries renowned.

2. The Lower Harz consists principally of graywackes, clay-slates and shales with Devonian fossils and some graptolites. The series has been named from the Harz *Hercynian*, and corresponds to Barrande's *Etages* F, G, H, which occupy a position intermediate between the Silurian and Devonian systems of the Bohemian basin. Patches of Devonian rocks occur at several parts of the Lower Harz associated with intrusive and interbedded diabases and tuff-beds.

The Upper Harz contains, in addition to Devonian sandstones, shales and limestones, a large area of graywacke and shale, which extends over

* An extended description of the geology of the Harz Mountains, with illustrations, map and sections, and with a list of the most important German papers on the subject, is given by the author in the *Proc. Roy. Phys. Soc. Edin.*, Vol. VIII., 1883-4, pp. 207-266.

the western and southern parts of the district, and was found by Murchison to be of Culm or Lower Carboniferous age. The Hercynian rocks are developed only in the south-western corner of the Upper Harz between Herzberg and St. Andreasberg.

The huge granite boss of the Brocken, believed by the old disciples of Werner to form the foundation of the "transition series," is one of the newest rock masses of the Harz. It rises as a great stock-like mass through the palæozoic formations, sending out apophyses or offshoots into the surrounding strata, which have been highly altered by the contact metamorphism produced in its vicinity.

Many dykes and bosses of basalt, diabase, kersantite, quartz- and orthoclase- porphyry, gabbro, syenite and enstatite rock traverse the palæozoic series, some of which are younger, but the majority either contemporaneous with, or older than, the granitic masses.

The palæozoic core of the Harz passes on its eastern, southern, and western sides underneath the slightly undulating formations of the plain. The old rocks are generally highly contorted, and strike as a rule north-east and south-west. The newer formations, beginning with the Upper Coal Measures and Red Permians, appear along the flanks of the Harz and rest in violent unconformability on the older strata. There must therefore have been a great upheaval and denudation between the time of the Culm and that of the Upper Coal Measures. The latter are generally overlapped by the red sandstones, shales and porphyrites of the Rothliegendes or Lower Permian group. These are in turn overlapped by the limestones and gypsum beds of the Zechstein or Upper Permian series which, along the western flanks of the Harz, creeps up over the Culm graywackes and completely conceals the underlying beds of the Rothliegendes.

The Harz is bounded on the north by a huge fault which runs for a distance of over 40 miles along the base of the mountains, and abruptly truncates the palæozoic rocks of the core. The edges of the secondary rocks are bent upwards and actually inverted along the line of fault, so that they appear to dip inwards below the mountains. The lowest beds are concealed, and no basal unconformability is to be seen on the down-throw side. It is only at Ballenstedt, near the eastern end of the fault, that the unconformability on the upthrow side has escaped removal by denudation. The Coal Measures and Red Permian sandstones are there found resting in a thin cake on the edges of the core rocks, in the same way that the Old Red Sandstone rests unconformably on the Highland schists on the north side of the great Caledonian fault between Crieff and Cortachy in Forfarshire.

Conglomerates containing pebbles of Harz rocks occur in the Coal Measure and Permian beds at Ilfeld on the southern side of the range. The highest of these conglomerates forms the basement of the Zechstein group, but from this horizon upwards to the tertiary deposits no trace of palæozoic detritus is to be found in any of the secondary strata. The ancient Harz must have begun to sink during the Permian period, and become completely submerged ere the Zechstein was all laid down. The emergence did not begin till the Cretaceous period, when signs of earth movement began to appear. The whole country was laid bare after the deposition of the Senonian or Upper Cretaceous group, and has since remained exposed to sub-aërial denudation, which has entirely removed the mesozoic covering as well as much of the palæozoic core below. The great brown coal deposits of Germany were formed in hollows or lakes during the Oligocene period, and one of these occurs in the neighbourhood of Thale and Blankenburg near the eastern end of the great fault. The brown coal here lies in a hollow, one end of which is clearly within the palæozoic area, and the other on the top of the Zechstein, which is here very thin and tilted up on end against the face of the fault. The fact of the deposit thus crossing or at least lying on the top of the line of dislocation, proves that the relative motion had entirely ceased previous to the Oligocene period.

3. The Upper Harz is traversed by a series of great faults which run through the highest Culm beds and also through the granite which pierces them. The faults must thus have been formed after the irruption of the granite. They run outwards to the edge of the range, and pass below the Zechstein, which abruptly cuts them off along with the quartz porphyry dykes which have sometimes risen along the lines of fissure. The faults are thus of Upper Carboniferous age, as they have evidently been formed between the time of the Culm and that of the Rothliegendes, when the porphyries were injected. They were certainly formed long before the Upper Permian period, as the Zechstein beds were laid down after the rock masses on each side of the faults had ceased to move, and had been planed off to an equal level by sub-aërial denudation. The series of faults runs from west to east past Clausthal towards Altenau. Similar faults cross the Bruchberg, a high spur of the Brocken between Clausthal and St. Andreasberg, and run into the St. Andreasberg mining district about 10 miles south-east of Clausthal, truncating or traversing the south-western end of the granite at that locality. The main faults at St. Andreasberg are generally parallel to those at Clausthal, and the two systems of dislocation are with good reason supposed to be contemporaneous in origin, although no faults have been actually traced the whole

distance from one locality to the other. If the faults which run westwards from Clausthal and pass under the Zechstein be thus contemporaneous with the Andreasberg faults farther east, the age of the granite is at once accurately determined. It must have been injected during the Upper Carboniferous period. The great metallic veins of the Upper Harz are in the fissures produced by these faults. The veins of the Clausthal plateau are either in the graywackes and "posidonomya shales" of the Culm, or else between Culm and Devonian rocks which, to the north of Clausthal, are brought together by a fault with a downthrow of over 100 fathoms.

4. The Clausthal veins are mined for lead, copper, and zinc, and are all very similar in mineralogical character. Dr. A. von Groddeck, Professor of Mineralogy and Geology, and Director of the Royal Mining Academy at Clausthal, is the author of one of the best existing works on Ore Deposits.* He has adopted the plan of classifying them according to certain types usually named after a locality where they are most strikingly developed. Veins similar in geological and mineralogical character to those of the Upper Harz are thus brought together under what he has named "Type Clausthal." This type is characterised by "Veins in stratified rocks of various ages, containing argentiferous galena, zincblende, copper and iron pyrites, with quartz, calcspar and chalybite in all proportions, barytes and other minerals occurring subordinately."

The Clausthal veins are large, sometimes reaching a thickness of over 130 ft. The footwall is sharply defined, but the hanging wall is usually shattered and rough, and passes into a fault-breccia containing fragments of graywacke and shale. It is a curious fact that calcspar is only found in the area north-east of the Innerste Valley and northwards from Clausthal, while barytes is confined to the portions of the veins traversing the western and south-western parts of the Upper Harz plateau. The ore is distributed in diagonal bands (*Erzfälle*) which slope towards the west, but occasionally occurs in vertical ribs (*Erzsäulen*) coinciding with the direction of hade, usually to the south. The same diagonal system of distribution obtains in the galena vein formerly mined at Tyndrum in Perthshire.†

The Clausthal mines are worked by the Prussian Government, and have now reached a depth in some shafts of 400 fathoms. There is a magnificent series of dressing works, to which the ore from the various mines is

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* "Die Lehre von den Lagerstätten der Erze." Leipzig, Veit und Co. 1879.

† See description of the Tyndrum mines, by J. S. Grant Wilson, and H. M. Cadell, in *Proc. Roy. Phys. Soc. Edin.*, 1883-4, p. 195.

brought. A great subterranean canal, communicating with a main drawing shaft at the dressing floors, connects the underground workings, and serves both as a mode of transit for the ore and as an adit level to drain the mines in the Clausthal district. The most improved systems of mining and dressing the ores are adopted, and new apparatus is from time to time introduced. At Clausthal there is a Royal Mining Academy, where students are well trained in the theoretical as well as the practical branches of metal mining, and have altogether exceptional opportunities for visiting the numerous mines, dressing floors, and smelting works, on and around the Harz, to which they have at all times free access. Coal does not occur on the Harz in workable quantity, and water is largely used as a motive power. The whole plateau of the Upper Harz is dotted over with artificial ponds and reservoirs, many of which are picturesquely situated in sequestered spots among the fragrant pine forests with which the whole region is densely clothed. The water is brought in neatly cut channels from the ponds to the wheels and dressing floors at the mines. Many of the waterways are very long, one of them which comes from a shoulder of the Brocken reaching a length of some 16 miles. They wind pleasantly about among the forest glades, sometimes crossing a valley on the top of a high embankment, and at others plunging into a shaggy mountain side to reappear and resume the even tenor of their way in the valley beyond.

5. The celebrated silver veins of St. Andreasberg are all situated within an area resembling a very obtuse isosceles triangle whose base is about 4 miles in length. Two sides of the triangle are barren fault fissures (*faule Ruscheln*) full of soft fault-rock, made up chiefly of fragments of clay, slate and shale. These have a southerly hade and a breadth sometimes reaching 200 ft. The silver veins are thin, seldom exceeding half a yard in thickness. None of them pass out of the area just described: all outsiders are base, containing only copper pyrites and ironstone. The argentiferous veins run roughly in two directions: the first set, containing several veins, has an average strike of E 60° S and a steep hade to northeast, while the two veins of the second system run approximately E 15° S and hade to north at an inclination of 60° to 85°. In the network of veins thus formed are found the many rare and valuable minerals for which Andreasburg has so long been famous. The silver veins are filled chiefly with turbid white calcspar, which encloses grains, strings, and nests of quartz, and occasionally fluor, while splendid drusy cavities with crystallised calcite, apophyllite, and other zeolites, are often disclosed. The chief metallic minerals are galena, zinc-blende, native arsenic, ruby silver (pyrargyrite), antimony silver, arsenic silver, silver glance, smaltine, Breit-

hauptite and kupfernickel. The cobalt and nickel ores occur only in subordinate quantities. It has always been found that the silver veins become barren where they have a great thickness.

The Andreasberg veins are thus essentially different in mineralogical character as well as in dimensions from the great lead and copper veins of Clausthal. They resemble the veins of Przibram in Bohemia, and are cited by von Groddeck as examples of his "type Brand," named from a district near Freiberg where great numbers of such veins occur.

6. The origin of metallic veins has been explained by four theories—the *Congeneration theory*; the *Lateral Secretion theory*; the *Descension theory*; and the *Ascension theory*. Each is no doubt true in particular cases, but as a general rule the last three are alone applicable to the great majority of mineral veins. Of these the descension theory has perhaps the least support, but on considering the circumstances connected with the formation of the majority of the veins of the Upper Harz, it appears to me that perhaps this hypothesis is worthy of more attention than it usually receives.

The Harz formed part of a terrestrial area during the Upper Carboniferous and Lower Permian periods, as we have seen. The upturned and contorted Devonian and Lower Carboniferous strata were faulted and subjected to sub-aerial denudation, which went on till the beginning of the Zechstein or Upper Permian period, when the whole region became completely submerged. The highest of the conglomerates derived from the erosion of the ancient Harz occurs at the base of the Zechstein series. It is overlaid by the celebrated seam of Kupferschiefer or copper shale, extensively mined in the Mansfeld district at the south-eastern extremity of the range. The Kupferschiefer is only about 18 inches in thickness, but extends over a very large area, as it is found cropping out along the whole southern border of the Harz, and also on the flanks of the Thüringerwald, in Saxony. It is simply a bituminous shale containing small quantities of metallic sulphides in the form of very fine particles or powder. The chief minerals are copper and iron pyrites, erubescite, copper glance, silver glance, zinc-blende, galena, kupfer-nickel, and smaltine. Although the shale contains not more than 2 to 3 per cent. copper, and 0·01 to 0·20 per cent. silver, and the workable part of the seam is less than a foot in thickness, it is very uniform in quality over large areas, and the great difficulty and expense incurred in sinking deep shafts through watery strata is amply repaid by the value of the silver and copper extracted. The area in which the shale was deposited must have contained large quantities of metallic matter in suspension or solution. It was inhabited by an abundant fish fauna, represented by the species *Palaeoniscus Freieslebeni*, and *Platysomus gibbosus;* many beautiful specimens of which are from time to time exhumed by the miners. The fine mud being deposited uniformly over the sea bottom, was mixed with particles of decomposing organic matter, which reduced and precipitated as sulphides some of the suspended metallic ingredients in the water.

The metals in the shale were no doubt derived from the denudation of rocks containing small quantities of metallic matter, in the form of silicates, oxides, or sulphides. Felspars have been found to contain small quantities of metallic matter, and as nearly all crystalline rocks contain much felspar, their decomposition would set free the metallic constituents. These would be carried off in solution if the water contained a sufficient quantity of solvents to prevent their immediate precipitation. Sulphides also occur abundantly, particularly in the palaeozoic formations, and the Harz contains one very remarkable contemporaneous deposit of this character in the celebrated pyrites bed of the Rammelsberg, near Goslar. The ore deposit of the Rammelsberg is interbedded with upper Devonian shales, and has been disclosed to a longitudinal distance of 1,400 yards, a thickness sometimes reaching over 60 feet, and an extent along the direction of dip of nearly 1,000 feet. It consists of laminæ of copper, iron, and arsenical pyrites, with argentiferous galena, zinc-blende, fahlerz, and other minerals regularly interbedded, and partaking of the crumplings and folds of the surrounding rock. For aught that can be proved to the contrary, there may have been similar deposits in parts of the Harz and other districts, removed by denudation during the Permian period, which may have added considerably to the proportion of metallic matter in the Kupferschiefer lake.

When the Kupferschiefer was being deposited over the floor of the basin, the newly submerged faulted area must have been covered by the Zechstein sea, and the metalliferous fluids would have free access to the fissures below. The metallic ingredients in the shale probably represent only a small percentage of the total quantity originally suspended or dissolved in the water, and their precipitation was no doubt regulated by the quantity of organic matter set free. The deposit has evidently accumulated very slowly, and the fissures may have remained open to the metalliferous fluids for a very long period before a change of conditions stopped its further deposition, and the basin became part of a great salt sea on whose floor the overlying limestones and anhydrite beds were precipitated.

I am well aware of the many difficulties with which the hypothesis I have thus roughly sketched out is beset. I have ventured to bring it forward merely by way of suggestion, as it seems to me there is much room for investigation into the origin of metallic deposits, from the point of view of the geologist as well as from that of the mineralogist and chemist. Too much faith is sometimes placed in the operation of imperfectly understood subterranean agencies, and this is an example of a possible explanation of perplexing phenomena by an appeal to known agencies which have acted at the surface, and can there be investigated with tolerable security and ease. I am quite prepared to see the theory very much modified, or even altogether rejected, but I think that sub-aërial agencies may have had more influence on the formation of metallic veins than is usually supposed, and that the Descension theory deserves more respect than it generally receives.