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THE NATURE OF ORE DEPOSITS

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Besides the cobalt-nickel veins, the region also contains veins of carbonate spars free from cobaltiferous ores, especially an 8-meter (25-ft.) vein at the diorite contact, worked for siderite, and which is notable because it is accompanied throughout its entire course by a quartz vein containing chrome-mica.

The iron deposits of Dobschau still yield an annual production of about 35,000 tons, but the cobalt veins have been abandoned for some years. The total production reported from 1840 to 1880 was 26,000 tons of cobalt-nickel ore.

The cobalt veins of Thuringia differ from those of the Dobschau, just described, since they contain barite. They have been worked for many years, especially at Schweina, near Liebenstein.

According to Fr. Beyschlag[1] the veins are fault fissures with a steep southwest dip and a maximum thickness of 3/4 meter. The beds of the Zechstein formation, which dip southwest at 4½°, together with the copper-bearing layer of this formation, show a displacement along the veins of 3 to 8 m. (22 to 25 feet), and as much as 30 feet in exceptional cases. The vein filling consists of barite, calcspar, fragments of the country rock and smaltite, asbolite and erythrite. These vein fissures exert a remarkable influence on the bed of 'copper schist.' This Kupferschiefer is lean in this district, carrying only 1.4% of copper, and no silver, but, where it is traversed by the cobalt veins, it is enriched and holds 3 to 4% copper. At the same time the amount of copper in the uppermost layer of the Zechstein conglomerate, which immediately underlies the copper schist, rises from 3 to 10%. In particular the Beyschlag vein, discovered in 1901, proved very rich in ore.

Smaltite, niccolite, asbolite, rammelsbergite, erythrite and nickel green, (zaratite?) in subordinate amount, it is true, together with chalcopyrite and tetrahedrite, were also found in the copper veins of Kamsdorf and at the Rothen Berge at Saalfeld (see p. 227). Barite and various carbonates, especially siderite, are the prevailing gangues.

The fault fissures known as 'rucken' in the Mansfeld copper district also contain occasional nickelite, together with chalcocite, bornite, chalcopyrite, pyrite, calcspar, brownspar, ironspar, barite and rarely also rammelsbergite[2].

Similar lodes in Paleozoic schists were formerly worked at Lobenstein, in the principality of Reuss.

Other veins occur at Nanzenbach, near Dillenburg, in Nassau, in paleo-

[1] F. Beyschlag: 'Kobaltgänge von Schweina.' *Zeit. f. Prak. Geol.*, 1898, pp. 1–4.

[2] Baeumler: 'Ueber das Vorkommen von Nickelerzen im Mansfeldischen Kupferschiefergebirge.' *Zeits. d. D. G. G.*, Vol. IX, 1857, pp. 25–50.

picrite and volcanic tuffs[1]. They carry siderite, ankerite and quartz as a gangue, containing nickel pyrite and bismuth glance, nickeliferous iron pyrite, copper pyrite, and some ores of secondary formation.

21. Quartz-Cobalt Veins.

(Quartz-Cobalt-Bismuth Deposits.)

One of the best known examples of this type is the cobalt district of Schneeberg, in Saxony, a mountainous region 1,300 to 1,600 feet (400 to 500 m.) above the sea, in which clay slates of the Phyllite formation of the Erzgebirge adjoin Cambrian mica schists, and are intruded by the great granite stocks of the western Erzgebirge. Most of the veins outcrop in the interval between the granite masses of the great Eivenstock, Kirchberg and Schlema. This entire mass of schistose rocks has been altered by contact metamorphism, but small remnants show the original nature of the rocks. The contact zones are particularly marked, because the top of the granitic intrusive masses almost everywhere dips gently under the schists, being partly concealed by them, as may be seen by an examination of Dalmer's sections[2], Fig. 182 and 183. The country rock is partly normal phyllite and clay slate, but mainly metamorphic rocks resulting from the contact action of the granite, particularly carpolite, hornfels and andelusite-mica rocks, as well as striped augite-hornblende schist. In addition to this the Eibenstock tourmaline-granite and the porphyritic granite of Oberschlema are also present.

Besides quartz-cobalt veins the Schneeberg district contains quite a variety of vein types, which, according to the monograph of Müller[3] and later communications by H. Tröger, are divided into two main groups, an older and a younger.

The older veins include tin deposits, the quartz-copper veins and pyritic-lead veins, as well as barren quartz veins, deposits which have in part been already mentioned in their proper place in this work. The younger vein group is, on the contrary, made up of quartz-cobalt veins, rich cobalt-silver veins and lastly the iron ore deposits.

The class of quartz-cobalt veins, also called cobalt-bismuth veins on account of their high percentage of bismuth, are decidedly the most economi-

[1] v. Koenen in *Zeits. d. D. G. G.*, 1863, Vol. XV, p. 14. E. Frohwein: 'Beschreibung des Bergrevieres Dillenburg.' Bonn, 1885. W. Riemann: 'Der Bergbau und Hüttenbetrieb der Lahn-, Dill- und benachbarten Reviere.' Wetzlar, 1894, p. 37.

[2] K. Dalmer, E. Köhler and H. Müller: 'Section Schneeberg der geol. Spezialkarte von Sachsen nebst Erläuterungen.' 1883.

[3] H. Müller: 'Der Erzdistrict von Schneeberg im Erzgebirge.' B. v. Cotta's Gangstudien, 3d Ser., 1860, pp. 1-223; with bibliography.

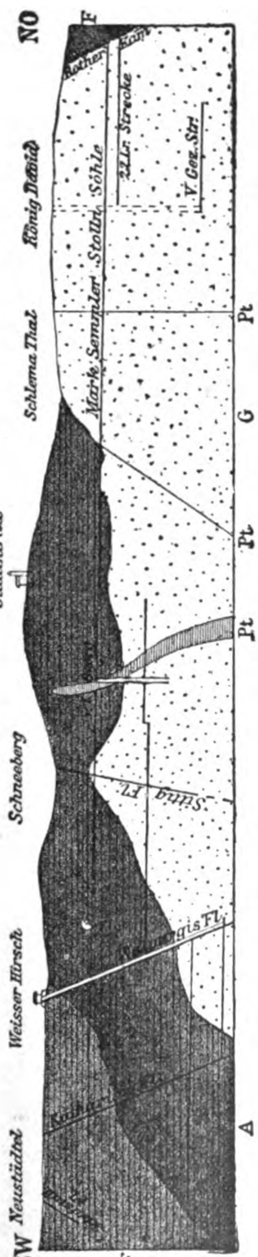


Fig. 182.—Section through the northern part of the Schneeberg cobalt district. (K Dalmer.) F, carpolite; A, andalusite-mica rock; G, granite of Schlema; Pt, porphyrite.

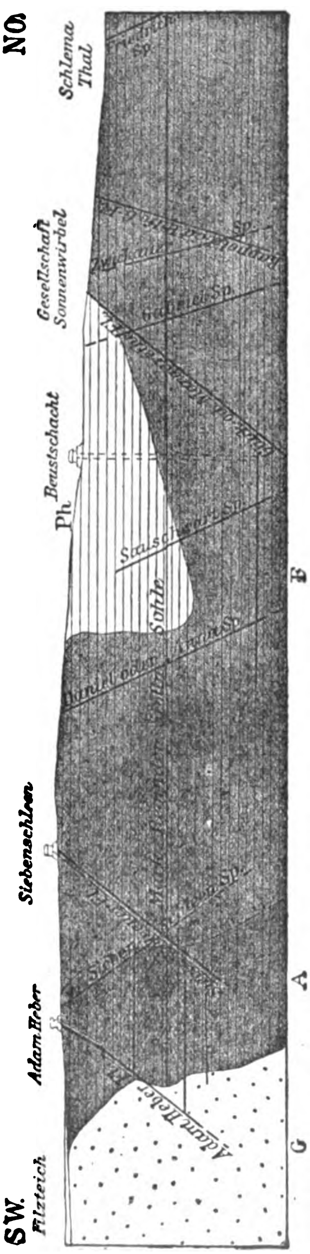


Fig. 183.—Section through the southern part of the Schneeberg cobalt district. (K. Dalmer.) Explanation as in Fig. 182. Ph, phyllite.

cally important deposits of the entire district. At Schneeberg, the veins are so crowded together in an area but 3 miles long and 2 miles wide, that Müller called the whole area a stockwork. Over 150 lodes have been exposed in mining. The veins occur in two bands, intersecting at an acute angle. One of them strikes northwest to north-south, the other west-northwest to northwest. In both systems the dip is steep, mostly 60° to 80°, partly northeast, partly southwest. The thickness varies between 2 centimeters and 3 meters, but is mostly less than 0.5 meter. Many show a decided tendency to stringers, and the junctions of such stringers are apt to be especially rich.

The fissure filling consists mainly of disintegrated, decomposed and partly mineralized and silicified country rock. The gangue minerals include quartz, mostly finely granular, crystalline and transparent, a gray and red hornstone, and some chalcedony and jasper. Carbonates such as calcspar, brownspar, rhodochrosite colored by cobalt, etc., are less prominent, and barite and fluorspar are very rare. The carbonate minerals are more common in vugs than in the solid vein filling. Calcspar occurs in a great variety of crystalline forms, especially prisms with one or two flat rhombohedrons and disc-shaped, perfectly flat rhombohedron combinations, the so-called paper druses, for which Schneeberg is famous. The most frequent ore minerals include smaltite in two varieties, one tin-white, the other a gray granular or crystalline variety rich in iron, chelentite (bismuth-cobalt-pyrite), asbolite, and erythrite, which also occur in large stalactites of recent formation. The nickel ores include rammelsbergite and smaltite, native bismuth, often in magnificent aggregates of netted crystals, bismuth ochre, and finally pyrite. Among the rarer ingredients are bismutite, bismuthinite, eulytite, cobaltspar, pucherite, roselite, native silver, argentite, proustite, pyrargyrite, polybasite, and other rich silver ores, marcasite, arsenious pyrite, native arsenic, uranium pitchblende (now famous as the source of radium), autunite, and the rarer uranium ores, trögerite, walpurgite, zeunerite, uranospinite, uransosphaerite, occur in the Walpurgis veins. Copper ores, zinc-blende, galena, etc., occasionally occur.

Among the gangues mentioned above, the quartz and the other siliceous minerals did not constitute the original and characteristic accompaniments of the cobalt and bismuth ores of Schneeberg. The carbonates, especially brownspar and calcspar, were formerly far more abundant, probably in association with barite, but were in part subsequently removed and replaced by silica. This is shown by the pseudomorphs for which Schneeberg is well known, consisting of quartz and hornstone, rarely also of chalcedony, after calcspar and sometimes after barite. The first named often contain a core of undecomposed calcspar. The latter are apt to represent large-celled aggregates of intersecting plates composed of a multitude of small quartz crystals with empty interspaces, showing that the replacement is not yet completed. Pseudomorphs of this kind have been found, in a half-finished condition, as it were, being soft and crushable with the finger, but hardening into a crystalline quartz mass on exposure to the air[1].

Certain cobalt veins of this locality are still composed almost wholly of carbonate minerals to a considerable depth, contrary to the general rule; they thus form a transition between the quartzose, Schneeberg type and carbonspathic cobalt-nickel deposits. Thus large parts of the Adam Heber vein consist of nothing but brownspar and some calcspar, and it is seen that the ores are here developed in different proportions. Chloanthite and niccolite predominate and carry 6 to 8% or even 20% of silver. In this gangue uraninite (pitchblende) also occurs, while in those portions where this lode carries its normal siliceous gangue, smaltite and native bismuth are also present.

The gossan of the Schneeberg cobalt-bismuth veins is unusually deep, extending down for 425 to 550 feet, and seldom as little as 250 feet. In the gossan, bismuth ochre and the other oxidized ores occur, sometimes in rich workable orebodies close to the sod. The vein filling is in most cases irregularly massive, more rarely banded.

H. Müller has shown that in general the cobalt-nickel ores and bismuth ores are found where quartz and hornstone predominate over the carbonates; that the rich silver ores occur mainly associated with calcspar; that nickel ores occur especially in the initial and terminal parts of the cobalt orebodies and that uraninite (pitchblende) is as a rule associated with chalcopyrite and galenite.

In late years it has been proved that as a rule the Schneeberg veins become barren where the fissures pass into the underlying granite. Only in exceptional cases, as in the Katharina vein on Weisser Hirsch, do the rich cobalt ores extend for any considerable distance downward into the granite. The vein just named shows a remarkable impregnation of the granite with pitchblende. It was observed in the foot-wall country rock on the 850 foot cross-cut, although the vein itself had, above the level, ceased to show the uranium ores mined near the surface. In this very peculiarly limited and slight downward extension of their orebodies, the cobalt veins resemble the tin lodes. Like them they are genetically connected with the intrusive granite massives and occur only above them or in their uppermost parts. No workable orebodies have thus far been found in the Schneeberg

[1] This structure is common at the Drumlummon (Montana), De Lamar (Idaho) and other American mines. It is forming at Boulder Hot Springs (Montana), and has been observed at Guanajuato, Mexico, and Leon, Nicaragua, by W. H. W.

mines deeper than 460 to 480 m. (1,500 to 1,600 ft.) The cobalt-silver veins of the Schneeberg cobalt district merit a few words. Only a few veins of this type are known, but they were very rich in silver and the development of the district and the building of the town resulted from their discovery and wealth. They show a great resemblance in their whole development to those of Annaberg, previously described. The large amount of barite in the gangue led Müller to designate them as barytic cobalt-silver deposits.

Very frequently the ores are a secondary or later deposit in an older primary filling of veins of the group just discussed. The later filling, itself, however, sometimes has been reopened and filled with iron-and-manganese ores. The vein filling, therefore, consists of quite heterogeneous constituents. The gangue consists of coarsely foliated barite, less frequently fluorspar, brownspar, calcspar, and quartz; the ore minerals are cobalt, nickel, and bismuth sulphides, slightly argentiferous galena, the rich silver sulphides and polysulphides, as well as iron and manganese ores.

A famous example is the Sanct Georg or Michael vein, mined to a depth of 760 meters (2,500 ft.).

The iron-manganese veins of Schneeberg are also important, since they fault the cobalt veins. One of the most important of these fault veins is the so-called Rothe Kamm, which, striking north-northwest, cuts off sharply the granite bodies of Oberschlema and Auerhammer, and may be traced for a distance of 5 kilometers. Lastly, this remarkable district contains the so-called Schwebende lodes, zones of strongly fractured and altered rock, running parallel to the stratification of the slates, and impregnated with some quartz, brownspar, galenite, arsenopyrite, pyrite, chalcopyrite and brown hematite. At intersections with transverse veins they became a little richer and have at several points been worked for silver. Mining at Schneeberg was originally confined to its very rich silver veins, but this gradually declined and mining only recovered when the employment of the cobalt for the manufacture of dyes gave a value to this formerly neglected metal. In 1540 the first bluing works were established at Platten in the Erzgebirge. The mining industry was stimulated anew by the increasing employment of nickel and bismuth in the metal industry; among other things by the invention of German silver by E. A. Geitner in Schneeberg in the beginning of the twenties of the 19th century.

The cobalt mines of Schneeberg are now owned by the Royal Treasury of Saxony and by the Sächsiche Privat-Blaufarbenwerks-Verein. The output in 1898 was only 307.7 tons of argentiferous cobalt-nickel and bismuth ores.

Remarkable cobalt veins exist at Balmoral, east of Pretoria, in the

Transvaal. They consist of hornstone with actinolite, smaltite and erythrite. and occur in the schists of the Cape formation[1].

Surprisingly rich veins of cobalt-nickel arsenides, very rich in native silver, were discovered in slate at Haileybury, in Ontario, Canada, in 1903, while a railway cutting was being excavated.[2]

22. Veins of Hydrosilicate Nickel Ores.

This type of nickel vein occurs only within serpentine. The veins consist of garnierite, a mixture of hydrated nickel silicate in greatly varying proportions, usually carrying 6 to 12% of nickel, though perfectly pure portions are richer; of numeaite, distinguished from the preceding by its darker color and greasy feel; genthite, as the more highly nickeliferous varieties of garnierite are called; and pimelite, the aluminous variety, as well as magnesite, limonite, allophane, cerölite, chrysoprase, chalcedony and quartz. Ordinarily there are no large veins, but merely a network of small stringers in the serpentine.

The most important deposits of this class are those of New Caledonia[3], a long island extending from northwest to southeast, midway on the route from the Australian continent to the Fiji Islands. The veins occur especially in the environs of Numéa, Dombéa, Thio, Mont Mou, Mouéo and Gomen.

The most important deposits of this class are those of New Caledonia[3], pentine massives with which the nickel ore deposits are associated form rounded, dome-shaped elevations in sharp contrast with the jagged crests of the Archean rocks, and the gently undulating lands formed of the Triassic, Jurassic and Cretaceous beds. The veins and stringers of garnierite and numeaite are common at the boundary between the serpentine and the variegated clays resulting from the decomposition of the serpentine. These clays contain no nickel, but carry iron cobalt and chrome ores. The nickel-bearing serpentine stocks cover about 6,000 square kilometers, or one-third of the entire island. The nickel deposits were discovered in 1863 by J. Garnier, and described in 1867. The exportation amounted to 140,000 tons in 1901, the ores carrying 4 to 4.5% of metallic nickel. In the ores exported in former years the nickel content varied between 4.5 and 10%.

[1] G. A. F. Molengraaf: 'Geol. de la Rep. Sud Afrikaine,' 1901, p. 60.

[2] W. G. Miller: 'Cobalt-Nickel Arsenides and Silver,' *Report* Ontario Bureau of Mines, 1904, part I, pp. 96–103.

[3] J. Garnier: *Ann. des Mines*, 1867. A. Bernard: 'L'Archipel de la Nouvelle-Calédonie.' Paris, 1895. p. 458. Fr. Danvers Power: *Proc.* of the Inst. of Min. and Met., London, 1900. Vol. VIII, p. 44. Abstract in *Zeit. f. Prak. Geol.*, 1901, p. 24 *et seq.* G. Henriksen: 'Om Nikkelmalmen i Ny Caledonien.' Teknisk Tidskrift, February, 1902.

The production from 1896 to 1900 was 374,000 tons of nickel ore. The production of cobaltiferous manganese ores with 3 to 5% of cobalt oxide, found on the east coast of the island, is rapidly increasing.

J. B. Jaquet reports the occurrence of asbolite deposits in clay and serpentine, particularly at the boundary of these rocks[1] at Port Maquarie, in New South Wales.

An American district lies near the town of Riddles, Oregon. The rock in which the nickel veins occur has not been serpentinized to so great a degree as in New Caledonia. At Mount Piney, three miles west of Riddle, the rock is a remarkably fresh harzburgite, consisting of about two-thirds of olivine, with one-third bronzite, chromium and magnetite. According to J. S. Diller[2] the rock contains, among other things, 0.76% Cr_2O_3 and 0.1 NiO, while the olivine, though not absolutely free from bronzite and chromite, contains 0.79% Cr_2O_3 and 0.6% NiO. Even the unaltered olivine rock is traversed by serpentine veins. These contain a magnesia-nickel silicate resembling garnierite, but distinguished from it under the name of genthite, on account of its greater nickel content (12 to 29% NiO). This segregated at first in finely interspersed patches and small veins, accompanied by quartz and iron oxide. Little by little the rock is traversed by so dense a network of such veinlets that it assumes a coarsely netted or brecciated structure. Finally larger accumulations of genthite are formed, which, always associated with quartz and chalcedony, fill the fissures, sometimes with distinctly bedded arrangement. The change in volume of the original olivine rock by the absorption of water during serpentinization favors the formation of stringers, which is the dominant characteristic in the development of these lodes. Another nickel locality of great scientific interest is Webster, North Carolina.

In recent years nickel has been extensively mined at Frankenstein[3], in Prussian Silesia. The deposits occur in the Gläsendorf-Kosemitz serpentine range, whose rock, besides remnants of olivine, contains magnetite, chromite and abundantly disseminated prisms of tremolite. This serpentine is cut by numerous long fissures, mainly filled with a brownish red friction product, usually distinctly brecciated, consisting of serpentine and

[1] *Australian Mining Standard*, February 17, 1898.

[2] F. W. Clarke: 'Some Nickel Ores.' *Amer. Journ. of Sc.*, Vol. XXXV, p. 483. H. B. von Foullon: 'Ueber einige Nickelvorkommen.' *Jahrb.* d. k. k. geol. Reichsanst., 1892, Vol. XLIII, part 2. W. L. Austin: *Zeit. f. Prak. Geol.*, 1896, p. 203.

[3] J. L. Meinecke: 'Ueber den Chrysopras und die denselben begleitenden Fossilien in Schlesien.' 1805. J. Roth: *Erläut.* zu der geol. Karte vom niederschlesischen Gebirge, 1867. B. Kossmann: 'Die Nickelerze von Frankenstein in Schlesien.' *Berg u. Hutten. Zeit.*, 1890, pp. 111-113. Also Essener Glückauf, 1893, No. 54. H. B. von Foullon: *op. cit.*, p. 257 *et seq.*

talc and ferruginous clay. At the selvage the filling sometimes assumes a thinly foliated structure as a consequence of great pressure. These veins, which are associated with imperfectly defined zones of disintegration, are themselves traversed by numerous stringers, often either mere plates several cm. thick, or irregular veins, of pimelite, garnierite, cerolite, sepiolite, schuchardtite (an aluminous magnesium hydrosilicate with 8 to 17% nickel), quartz, hornstone, white opal and chrysoprase. Brown red masses with scattered spots or nests of pimelite, locally called nodular ores, occur irregularly scattered through the broad lodes and sometimes form large stocks. Among the cobalt ores earthy erythrite may be mentioned as a rarity. At the present time the nickel deposits have been mined to a depth of 56 m. (183 ft.) Down to 52 m. (170 ft.) the mine was dry. Chrysoprase, the gem popular in the 18th century, was extracted as early as 1740, but nickel mining is of recent date. In 1901 9,500 tons of ore were extracted and 114.3 tons of nickel were produced. There was a considerable increase of production in 1902. Magnesite is also mined, especially from the Buchberg, south of Frankenstein.

The analagous deposits at Revda (or Rewdinsk), west-southwest of Ekaterinburg, in the Ural, are more siliceous than those just described. At this locality[1] a band of antigorite-serpentine is intercalated in a zone of crystalline schists and crystalline limestones. The serpentine has, according to H. B. von Foullon, been derived from a feebly nickeliferous pyroxene rock. In the serpentine which has thus become nickeliferous, a concentration of the nickel takes place on further decomposition, considerable amounts of silicic acid being segregated, together with hydrated nickel-magnesia silicates. Hence the ores consist in a large part of small nodules and fragments of nickel-magnesia silicates cemented by quartz into a breccia. The reopening of fissures and the continued deposition of silicic acid has, moreover, formed breccias consisting of quartzose nickel ore fragments, with a cement of pure quartz. The final result of the decomposition of the serpentine is a ferruginous residue containing pockets of nickel silicate, sometimes of asbolite. Sometimes these new formations have taken place in extensive fissures, which may be due to mountain-building forces. Thus H. Müller described from Revda a vertical vein over 2 meters thick in serpentine and adjoining chloritic schist. The filling consists mainly of corroded quartz and chrysoprase. In this lumps of nickel up to the size of an apple were found in cavities associated with fatty clays.

[1] H. Müller: 'Ueber die Nickelerzlagerstätten von Rewdinsk.' *Berg u. Hutten. Zeit.*, 1866, p. 65. H. B. von Foullon: *op. cit.*, p. 234 *et seq.* A. Karpinski: 'Ueber die Lagerstätten der Nickelerze im Ural' (in Russian). *Gorni Journal*, 1891, No. 10.

Quicksilver Veins.

The principal ore of this class is cinnabar. Accompanying this there are found, mostly in small quantities, native quicksilver, metacinnabarite and calomel. Associated pyrite always occurs, with occasional particles of marcasite and copper pyrite, more rarely stibnite, arsenopyrite, realgar and other sulphides. The principal gangues are quartz, chalcedony, opal, calc-spar and dolomite, very frequently also various forms of bitumen. Barite, fluorspar and gypsum are less frequent.

Besides true veins the quicksilver ores form impregnations in the adjoining disintegrated and much fissured rocks, or in originally porous rocks and may form stockwork orebodies.

Since the conditions at Sulphur Bank and Steamboat Springs have become known (see later), no one can doubt that quicksilver deposits are formed in the hydrothermal way. The quicksilver seems to have been in solution as $HgS+4Na_2S$, a double salt whose formation is readily possible in the presence of dissolved carbonates and sulphohydrates of the alkalies at a high temperature. The bituminous substances, which are almost always alongside of the cinnabar in Nature, seem to have served as the precipitant. But other modes of formation are conceivable, as for example, the manner suggested by V. Spirek, mentioned below.

As the first example we will describe Almaden[1], the most important quicksilver deposit of the globe. The town lies at the boundary between Andalusia and La Mancha, Spain, on the north slope of the Sierra Morena. The rocks consist of beds of steeply upturned shales of Silurian and Devonian age, with intercalated quartzites, which weather out in steep rocky outcrops. The strata are often interrupted by diabases and huge intercalations of igneous rocks.

The deposits consist of three quartzite beds impregnated with cinnabar. These beds have a mean thickness of 8 to 10 meters (26 to 32 ft.). The southernmost of these orebodies is called San Pedro y San Diego, the next is San Francisco and the northernmost San Nicholas. In the first named the impregnation is very strong, so that the quartz grains appear almost entirely displaced. In the other two the occurrence of the cinnabar is in the main confined to stringers and streaks, often forming parallel bands, but sometimes running cross-wise. The orebodies either adjoin barren quartzites (and in that case the boundary of the cinnabar ore is not sharp), or else the country rock is schist, in which case the ore ends suddenly.

[1] G. F. Becker: 'Geology of the Quicksilver Deposits of the Pacific Slope,' with atlas. *Monogr.* of the U. S. Geol. Surv., XIII, 1888, pp. 28–31. Fuchs and De Launay: 'Traité,' Vol. II, 1893, pp. 672–680. Caron: 'Bericht über eine Instruktionsreise nach Spanien.' *Z.* f. B. H. u. S. im preuss. St., Vol. XXVIII, 1880, p. 126.

According to H. Kuss, the zones of impregnation do not always follow one and the same stratum of the quartzite, but occasionally jump across to a neighboring stratum. An important feature is the occurrence of gliding planes in the schist and of displacements in the San Nicholas bed, as mentioned by Caron.

A little metallic quicksilver occurs with the cinnabar and pyrite, with some chalcopyrite. Gangue minerals are almost entirely lacking and comprise scanty amounts of barite and bits of bituminous substances, and, according to Becker, quartz.

With increasing depth these particular deposits have become richer, while in others in the vicinity, such as Almedenejos and Las Cuevas, the reverse occurs. Between 190 and 215 meters (625 and 705 ft.) the ore carried 8 to 20% of quicksilver. From 215 m. (705 ft.) downward, the rich ores, with 20 to 85%, first appeared, and became predominant below 263 m. (863 ft.) (De Launay).

The ancient Athenians are said to have known of the cinnabar deposits in this region. Pliny describes the locality under the name of Sisapo, the mines being worked in Roman times. They were again productive during the Moorish occupancy. From 1525 to 1645 the Fugger brothers exploited the mines. Between 1564 and 1895 the locality produced about 153,000 tons of quicksilver. In the nineties of the 19th century the average annual production was 1,700 tons of metal.

A second quicksilver field on the Iberian Peninsula, which may be mentioned in connection with Almaden, lies in Asturia, south of Oviedo and near La Pena, Lada, Otero and other towns. According to A. Dory[1], the occurrences at these localities are impregnations of cinnabar and a little metacinnabarite, amalgam, orpiment and realgar in breccias and quartzites of the Carboniferous limestone, as well as in conglomerates and sandstones, and even in coal beds of the Carboniferous. The ores of this region are much poorer than those of Almaden. For the most part they contain only 0.7% of quicksilver.

Next to Almaden the Idria deposit is the most important European locality.

Idria[2], in Carniola, Austria, lies 34 km. northwest of Loitzsch, between

[1] *Revue Univers. des Mines*, Liege, Vol. XXXII, 1895, pp. 209-297.

[2] M. V. Lipold: 'Mittheilungen über die geol. Verhältn. der Umgebung von Idria und der Erzlagerstätten daselbst.' *Jahrb.* d. k. k. geol. Reichsanst., 1853, pp. 422, 864; 1856, p. 838; 1857, p. 838. A. Schrauf: 'Ueber Metacinnabarit von Idria und dessen Paragenesis.' Same journal, 1891, p. 349. 'Geolog.-Bergmännische Karten,' with profiles of Idria and views of the quicksilver deposits of Idria, published by k. k. Bergbeamten. Vienna, 1893. Edited by k. k. Ackerbau-Ministerium. With complete bibliography. F. Kossmat: 'Ueber die geologischen Verhältnisse des Bergbaugebietes von Idria.' *Jahrb.* d. k. k. geol. Reichsanst. Vienna, 1899, Vol. XLIX, part 2.

Laibach and Görz. The deposits occur in an area of Alpine Triassic rocks, which have been distributed at this locality in a very complicated way by a number of faults and overthrusts, and have been broken into a group of fault blocks, with northwest strike. This structural condition, formerly difficult of comprehension, has been cleared up recently by F. Kossmat, from whose paper we extract the instructive cross-section of Fig. 184. The main lines of the stratigraphy had already been established by M. V. Lipold. The structural features of the mines are furthermore illustrated by a longitudinal section (Fig. 185), taken from the official work on Idria. The following table is a summary of the stratigraphic succession, as it is now understood, the table also giving the symbols of the formations shown in the section.

The section is as follows, from above downward:

Alpine Trias:
- 6. Raibl strata. } Not in the mines.
- 5. Cassian limestones and calcareous slates. }
- 4. Wengen beds, consisting of tufaceous sandstones and marls (t) with Daonella Lommeli Wism., besides intercalations of plant-bearing skonza slate (s).
- 3. Dolomites and dolomite breccias (d) as well as limestone conglomerates (c) of the Muschelkalk.
- 2. (b) Campil calcareous slate and marly limestone (kk) } Werfen strata grouped together as (w).
  (a) Seisser sandy shale and dolomites (ssch) }
- 1. Paleozoic Gailthal shales, the so-called silberschiefer (gsch).

By a comparison of this section, showing the relative ages of the beds with the two profiles, the existence of extensive overthrusts is at once apparent.

The quicksilver deposits of Idria consist only in small part of true veins, being mainly impregnations in country rock which are in part connected with large, well defined fissures, though this is no longer demonstrable, owing to the removal of material from the workings. They appear to form stratiform deposits. In both fissures and impregnations the mineralogic character of the deposit is simple. Cinnabar is the predominant ore. Native mercury is found as an impregnation, especially in the so-called 'silberschiefer' of the upper regions. Metacinnabarite is rare. Pyrite is very frequently present, especially as a companion of native quicksilver. The most abundant gangue minerals are quartz, calcite and dolomite; barite and asphalt-like minerals, as idrialite, occur. Flourspar is rare.

The mines occur in two groups, a northwestern and a southeastern.

The only distinctly vein-like deposits are found in the southeast mine, worked through the Joseph shaft. At this place the tuffs and marly slates of the Wengen formation rest on limestones and calcareous shales of the Werfen beds, as well as on dolomites and breccias of the Alpine Muschelkalk and are by faulting capped by dolomites and limestones of the Muschelkalk. Among the ore-bearing fissures traversing these sediments, there are two principal veins striking northeast and dipping 28° to 30° southeast. The vein filling is sometimes one meter thick and consists of limy, shaly, breccia-like rock, heavily impregnated with cinnabar, and mixtures of

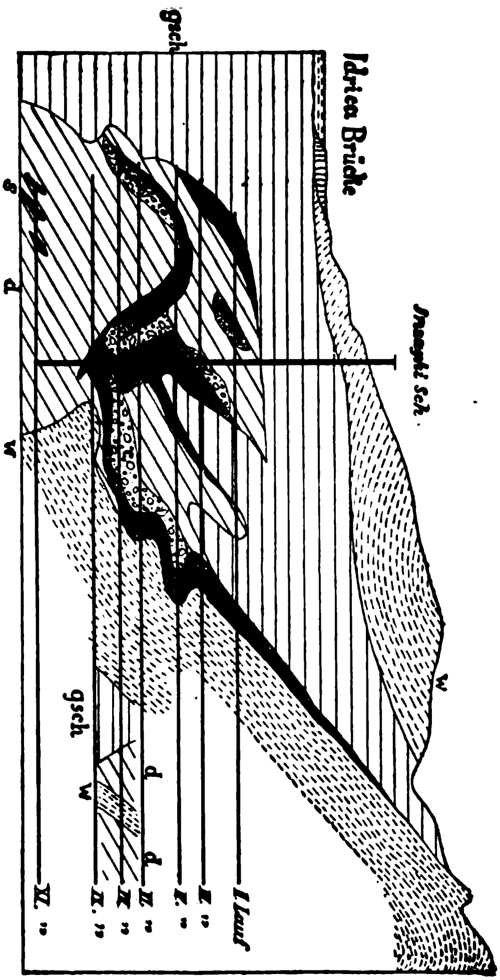


Fig. 184.—Cross-section through the Northwest mine of Idria. (F. Kossmat.) (Explanations of symbols in the text.)

dolomite and cinnabar, constituting what is called steel ore and brick ore, from the color. From these fissures the cinnabar extends far into the adjoining dolomites. A remarkable feature is the presence of the so-called "first and second riders" (thin hanging-wall veins). These strike northwest and dip 75° northeast, and thus run parallel to the main fault fissure, which at this place cuts through Triassic rocks. These satellite fissures are also filled with brecciated masses strongly impregnated with cinnabar. Ore is also extracted in this part of the mine from a zone of

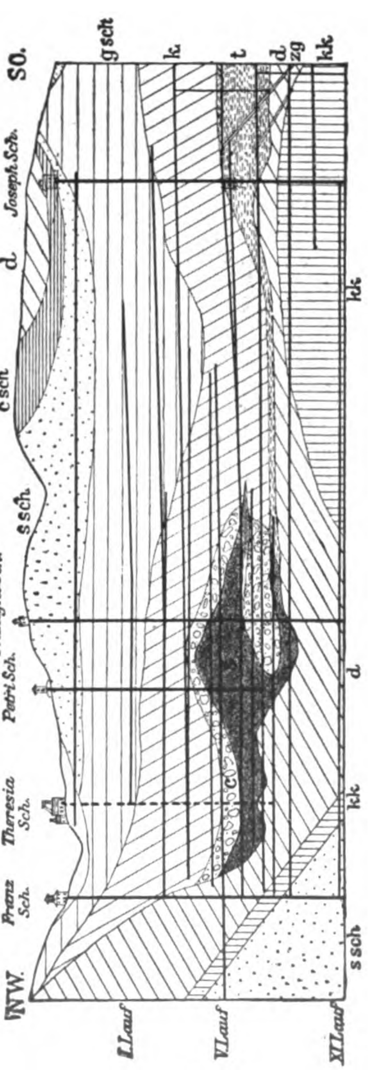


Fig. 185.—Longitudinal section through the cinnabar deposits of Idria. (J. Bloudek.) zg, cinnabar ore lodes. (Explanation of other symbols in text.)

impregnated rock lying along the bedding plane between the Guttenstein dolomite and the Wengen marly shales.

In the Northwest mine, on the contrary, the succession of rocks is different, for the Wengen tuffs and marly shales are replaced by the so-called

Skonza shales and limestone conglomerates. These Skonza shales or Lagerschiefer are dark gray to black, highly bituminous clay shales, which frequently contain plant remains. As a result of a pronounced imbricated structure of this faulted mountain block, the rocks are seen in certain sections repeated four times. The different strata have, as shown in the cross-section, been subjected to subsequent folding, together with the overthrust planes which delimit them. Extensive portions of these Skonza shales are heavily impregnated with cinnabar for 20 meters in thickness, the ore forming irregular pockets, kidneys, bunches and stringers or fillings along bedding planes. Moreover, the dolomitic conglomerates and breccias lying on and between the Skonza shales contain crystalline cinnabar regularly distributed in their cracks and fissures, while along the boundary between these rocks and the overlying Paleozoic silberschiefer (pushed over by overthrust faulting) finely divided native quicksilver is found.

The quicksilver ores, therefore, in the most important part of the Idria mines, have impregnated extensive masses of completely disintegrated rock, and have more or less saturated either highly porous or specially bituminous beds which acted as filters. The real channels of supply are not revealed. As the dislocations of the region are of Tertiary (probably Eocene) age it follows that the impregnation with quicksilver compounds is of very youthful age.

The only European district exceeding Idria in the production of quicksilver is Almaden. Its total output, from 1525 to 1895, is estimated at 58,000 tons of quicksilver. In 1898, 476.28 tons of metallic quicksilver were produced at Idria and 15 tons at Sanct Anna, near Neumarktl, in Carniola.

A noteworthy deposit of quicksilver ore occurs at Littai near the Sau. The distinctive feature of this deposit is the association of quicksilver and lead ores, the latter predominating. The ores occur in a zone 10 ft. (3 m.) thick of brecciated, shattered rock cutting an anticline of Carboniferous graywacke (a dark, tough sandstone composed of various minerals in angular fragments, firmly cemented). This orebody consists of much altered fragments of graywackes and some siderite cemented by galena, some blende, barite, chalcopyrite and pyrite. The cinnabar occurs only in and near fissures.

In the Apennines of Southern Tuscany, Italy, important quicksilver deposits are found, which are all the more interesting because their genesis is so evident. They occur within the volcanic district of Monte Amiata[1], but associated with very diverse rocks. The deposits are impregnations or bands of stringers, rather than true veins.

[1] P. de Ferrari: 'Le miniere del Monte Amiata.' Firenze, 1890. B. Lotti: 'Il

The principal deposit, at Cornacchino, west of Castellazzara, consists, according to B. Lotti, of clays impregnated with cinnabar, pyrite and gypsum. The clays are intercalated between the marly, flint-bearing limestones of the Upper Lias and represent the residue left by their decomposition by acid solutions, being the same solution from which the mercuric sulphide was precipitated.

The chemistry of this hydrothermal process has been investigated by V. Spirek. According to him the solutions contained sulphates of mercury, iron and other metals, and hydrogen sulphide, the latter gas being still given off from fissures in the earth at several points called 'putizze' in the Amiata region. At first calcium polysulphides and highly sulphuretted alkalies were formed, which, according to chemical experiments, were able to precipitate the mercuric sulphide from the solution, which meantime had become neutralized. The objection that K_2S_3 or CaS_3, by the surrender of two molecules of their sulphur, might readily be transformed into K_2S and CaS, which would redissolve the Hg that had been formed, is met by V. Spirek by the assumption that the HgS once formed was quickly enveloped in the clay mud, furnished by the corrosion of the marly limestones, and was thus protected.

The small cinnabar stringers in the underlying Liassic siliceous schists at Cornacchino are regarded by B. Lotti as secondary formations due to the removal of the ore from the overlying limestones by means of carbonated solutions.

Similar deposits of cinnabar in clay occur at Siele, between Santa Fiora and Castellazzara, where the deposit lies between marly Eocene limestones, whose fossils *(Globigerinae)* still show in the mineralized clay.

Near Montebuono cinnabar occurs in Eocene sandstones overlying Nummulitic limestones. This ore-bearing sandstone is friable, and partly disintegrated to a sand which has settled into cavities in the limestone.

At the Abbey of San Salvatore cinnabar is found in detritus on the mountain slopes, in solid Nummultic limestone, especially in the bituminous clay beds and in trachyte. In trachyte the cinnabar stringers are accompanied by marcasite and opal incrustations. Even at the present day acid sulphurous springs rise from this part of Monte Amiata. The quicksilver mining industry in the Monte Amiata region began in 1846, but

Campo cinabrifero dell'Abbadia di San Salvatore nel Monte Amiata.' *Rassegna Mineraria*, VII, No. 11. V. Novarese: 'Die Quecksilbergruben des M. A.' *Zeit. f. Prak. Geol.*, 1891, p. 60. R. Rosenlecher: 'Die Quecksilbergruben Toscanas.' *Zeit. f. Prak. Geol.*, 1894, pp. 337–353. Kloos: 'Zinnober führende Trachyttuffe vom Monte Amiata.' *Zeit. f. Prak. Geol.*, 1898, pp. 158–163. B. Lotti: 'Die Zinnober und Antimon führenden Lagerstätten Toscanas und ihre Bez. zu den quartären Eruptivg' *Zeit. f. Prak. Geol.*, 1901, pp. 41–46. V. Spirek: 'Zinnober am Monte Amiata.' *Zeit. f. Prak. Geol.*, 1902, p. 297.

assumed an active development only after 1866. The production in 1898 was 170 tons, the maximum having been reached in 1890 with 449 tons.

The most important quicksilver district of the Balkan peninsula is Avala,[1] in Servia.

At the Schuplja Stena, on Mount Avala, 24 kilometers south of Belgrade, a serpentine stock, intruded in dark gray Cretaceous limestone, is traversed by a quartzose lode 60 to 70 m. (197-230 ft.) thick, striking northeast to southwest, and dipping about 60° northwest. This deposit is itself in turn fissured by numerous east-west lodes, formed of many quartz barite veins and stringers carrying quicksilver ores. The common-

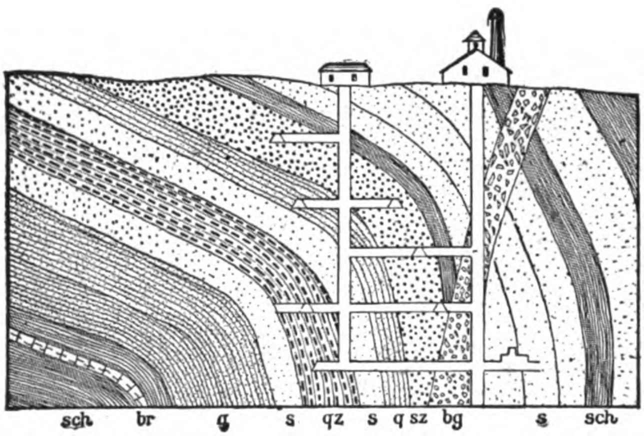


Fig. 186.—Cross-section through the cinnabar deposit of the Sophia shaft near Nikitovka. (Tschernyschew and Lutugin.)

sch, slate; br, breccia and conglomerate; q, quartzite; s, sandstone; bg, breccia vein; qz, quartzite with cinnabar; sz, sandstone with cinnabar.

est ore is cinnabar, but native quicksilver and calomel are also found. The quartz of the great northeast lode is often porous and hornstone-like and impregnated along well defined zones with iron pyrite, and with scales and fibers of a green micaceous mineral, carrying considerable chromium, and called avalite (Losanitsch). The deposit was discovered in building the Ljub. Kleritj Railway.

Quicksilver deposits are also known in Southern Russia, at Nikitovka, in the Donetz basin, along the Kursk-Kharkov Railway line. The cinnabar is, according to Th. Tschernyschew and L. Lutugin[2], found in fault fissures, in

[1] A. v. Groddeck: 'Ueber das Vorkommen von Quecksilbererzen am Avala-Berge bei Belgrad in Serbien.' *Preuss. Z. f. Berg-, Hütten- und Sal.-W.*, 1885, Vol. XXXIII, p. 112.

[2] *Guide des Excursions du VII. Congrès Géologique*, 1897, XVI, pp. 36–45.

coal, and as impregnations in the adjoining carbonaceous sandstones, quartzites and coal beds. The cinnabar is frequently accompanied by stibnite, pyrite and desmine. The accompanying section, Fig. 186, shows the structural conditions. The output in 1904 was 392 tons.

The quicksilver mines of the Palatinate, although long since worked out, are of scientific interest. They lie in the eastern part of the Palatinate-Saarbrücken coalfield.

According to von Dechen[1] and von Gümbel[2], the ores occur partly in veins, partly as impregnations associated with the veins, in beds of the coal series and the eruptive rocks intruded in them. At the Potzberg the veins occur in Carboniferous sandstone and clay slate, at Mörsfeld in the melaphyre conglomerate, claystone conglomerate and claystone, at Rathsweiler, Erzweiler and Baumholder in melaphyre; at Königsberg, near Wolfsberg, in quartz porphyry. Numerous parallel stringers accompany the lodes, and the country rock is ore-bearing, especially if it is sandstone and claystone. Some of the lodes have a remarkable length for this type of vein. The Gottesgabe vein at Landsberg is 900 meters long. In other cases the veins lie side by side with overlapping ends, forming a lode system 1 to 3 miles long, as at Stahlberg and at Kirschheim-Bolanden. The pay ore in these veins decreases rapidly in value below 656 ft. (200 m.)

The vein filling consists mainly of clay, in which the ore minerals, chiefly cinnabar, occur as veinlets, streaks or druses, more rarely in scales or ribbons of ore. Native quicksilver, amalgam, calomel, bituminous cinnabar and mercurial tetrahedrite also occur in the Landsberg "Black Vein." In rare cases pyrite, iron and manganese ores, galenite, native silver, chalcopyrite, stibnite, calcspar, barite, quartz, hornstone, ferruginous quartz and asphalt occur as accessory minerals, the gangue minerals forming, as a rule, only thin stringers or crusts.

A cinnabar deposit in Saxony[3], near Hartenstein, which has been known since the 16th century, presents unusual mineralogic characters.

The deposits occur as impregnations of chloritic clay and hornblende-slates of the Phyllite formation. The ore forms stringers and kidneys of quartz, feldspar, brownspar, calcspar and ironspar, accompanied by a little chalcopyrite and pyrite. At the Weidlich Stolln, which was operated towards the end of the 18th century, a lode 0.25 m. (0.8 ft.) thick, consisting of quartz, brownspar and ferruginous clays, was encountered near these impregnations. The cinnabar impregnation was also found in the Beständig

[1] *Karsten's Archiv.*, 1848, Vol. XXII, p. 375.

[2] W. v. Gümbel: 'Ueber die Quecksilbererze in der Pfalz.' *Verh.* d. naturw. V. f. Rheinl. u. Westf., VII, 1850, p. 83 *et seq.*

[3] H. Müeller: 'Der Erzdistrict von Schneeberg.' Gangstudien, III, 1860, pp. 170–174.

Glück Stolln, where it was confined to the vicinity of a small lode which was itself barren.

The greatest cinnabar deposits outside of Europe are those of California, described by Becker[1]. The deposits are mainly in the Coast Range, formed of folded metamorphosed Neocomian (Early Cretaceous) slates, with later intrusions of granite, quartz porphyry, andesite, rhyolite and basalt. The tilting and dynamo metamorphism of the Neocomian strata (*Aucella* beds) took place as early as the Middle Cretaceous, and was repeated with accompanying active volcanic eruptions. These eruptions, with which the quicksilver deposits are genetically connected, continue into post-Pliocene time.

The deposits consist of very irregular veins, often as the chambered veins described by Becker, or forming stock-like bodies which extend laterally from the lode into the shattered or porous country rock.

The following are the most important mining districts, given in the order of location from north to south: Sulphur Bank and other mines near Clear Lake in 39° north latitude, Great Western, New Almaden, northeast of Santa Cruz and New Idria. Sulphur Bank is described elsewhere.

The Great Western mines lie near the extinct volcano of Mount Saint Helena, in a region of metamorphic slate, intruded by andesite and basalt. The deposit forms a steeply inclined tabular orebody lying along the contact between slightly altered sandstone and an opalized serpentine. The ore contains cinnabar with pyrite in a quartzose gangue, with bituminous matter.

The New Almaden is the largest and most important of the cinnabar mines of California. The ores consist of cinnabar with some native quicksilver, and accessory pyrite, marcasite and chalcopyrite, in a gangue of quartz, chalcedony, calcspar, dolomite, and magnesite. The orebodies form stockwork 'chambers,' along two distinct lode fissures, in crushed and greatly disintegrated sandstones, serpentines and diabase-like metamorphic rocks.

A similar state of affairs prevails at New Idria, where the ore occurs within crush zones of the Neocomian strata. Bitumen is also present in these deposits.

G. F. Becker insists that no metasomatic replacement occurs in the Californian cinnabar deposits. He states that there has been no replacement of the country rock by the ores, but merely a filling of the existing pores, cracks and fissures. He regards the ores and gangues as deposits from hot springs which brought their mineral load from deep lying rock bodies. In 1902 California produced 29,199 flasks of 76.5 lb. of quicksilver,

[1] G. F. Becker: 'Quicksilver deposits of the Pacific Slope.' *Monogr.* XIII, U. S. Geol. Survey, Washington, 1888.

valued at $1,271,502. The Terlingua deposits of Texas produced 5,2 flasks in 1902. The ores occur as pockets of cinnabar with calcite gangue in fissure veins[1] cutting Cretaceous limestones. The total production of the world for 1904 was 118,711 flasks, or 4,010 metric tons.

In South America the cinnabar lodes of Huancavelica[2] in Peru were in former times of exceedingly great importance, having furnished 52,000 tons of quicksilver between 1571 and 1850. The town lies on the east slope of the western main ridge of the Cordilleras. The rock consists of Jurassic slates, conglomerates, sandstones and limestones intruded by trachytes. In the vicinity of the town are hot springs which deposit sinter so abundantly that it serves as building stone. They are the last phase of a dying volcanic activity. The Santa Barbara mine, close to the town, is the most important. The deposit consists of impregnations of cinnabar, pyrite, arsenopyrite and realgar in a sandstone.

The Huitzuco mines in Guerrero, near Chilpancingo, Mexico, should be mentioned in this connection. The ore is livingstonite, an antimonial sulphide of mercury, according to F. Pagliucci. It occurs in veins and replacements in cretaceous limestones, connected with well-defined hot spring conduits[3].

Recently the cinnabar ore lodes of Punitaqui in Chile have attracted attention[4].

The Chinese Empire was formerly a large producer of quicksilver, and contains, according to R. Pumpelly, quicksilver deposits in ten out of eighteen provinces of the empire, the most important being those of the province of Kwei-Chau. The mines at Kaitchou, a town near the provincial capital, Kweijang, have recently been re-opened by an Anglo-French Company.

Quicksilver ore lodes likewise occur in Asia Minor, at Habiler and at Haleköi[5].

In Australia also quicksilver deposits occur at Yulgibar in the basin of Clarence River in New South Wales, where three quicksilver veins have been opened. New Zealand contains deposits formed and now being deposited by the hot springs at Oheawai. (Parks.)

[1] B. F. Hill, *Am. Jour. Sci.*, 4th ser., Vol XVI, pp. 251-252. 'The Terlingua Quicksilver Deposits,' *Bull.* No. 4, Univ. of Texas Mineral Survey, Oct., 1902.

[2] G. F. Becker: *Monogr.* XIII, U. S. Geol. Survey, p. 21.

[3] F. D. Pagliucci, in *The Engineering and Mining Journal*, March 2, 1905, p. 417. 'Mines and Metallurgy of Quicksilver in Mexico,' *Trans.* Inst. Mining and Metallurgy, London, Vol. IV, p. 69, 1895-6.

[4] A. Götting: 'Die Erzgänge zu Punitaqui in Chile.' *Zeit. f. Prak. Geol.*, 1894, p. 224.

[5] K. E. Weiss: 'Lagerstätten in Westlichen Anatolien.' *Zeit. f. Prak. Geol.*, 1901, No. 7.

C. GENERAL DESCRIPTION OF MINERAL VEINS.

(Continued from page 226.)

DIFFERENCES IN VEIN CONTENTS AT DIFFERENT DEPTHS.

Since the time of Von Cotta it has been customary to describe as *primary* those differences below the water level which are observed in the character of the vein filling at different depths. This change may consist in a different mineralogic composition, and perhaps also in the structure of the original filling. The different sections of a vein might, therefore, belong to entirely different vein types under the classification adopted. Such cases are, however, comparatively rare. On the contrary, difference between the character of the vein filling near the surface and in depth are extremely common in most of the vein deposits as well as in stratiform and stocklike deposits. These superficial changes are *secondary,* and due to a superficial alteration of the deposit and the influence of descending waters. Let us first consider some examples of the first kind.

CHANGES IN CHARACTER OF PRIMARY VEIN FILLING WITH DEPTH.

There was in former times a widespread belief that veins gradually became barren as the distance beneath the outcrop increased. This change in character of primary ore would be, if true, very important from the practical point of view. This theory was probably founded upon the well known change in the veins when the transition from the gossan into the undecomposed primary vein filling occurs, in which of course a sudden and great impoverishment was naturally noted in many cases. From this it was inferred that the impoverishment would continue downward. This assumption is probably the basis of the older views that gold veins grow barren in depth, a view formerly current in California. Recent deep mining of gold veins in that country and in Australia have dispelled this fear. We know, for example, that some lodes in Victoria are still workable at a depth of 4,000 ft. In many cases local zones of impoverishment were encountered, which, by reason of the older, less perfect mining methods, or insufficient funds, could not be passed through. This gave rise to a belief in the impoverishment of veins in depth. A few courageous, far-seeing men had to engage in a laborious fight against this prejudice, as, for example, Freiherr von Herder[1], who planned in 1838 the

[1] Freiherr von Herder: 'Der tiefe Meissner Erbstolln.' Leipzig, 1838.

deepest drift in the Freiberg field, which was afterwards driven and finished (the Rothschönberger Stolln). In some cases, indeed, the idea of an impoverishment in depth proved to be true, as for example, in the so-called cobalt ledges or 'rücken' of Thuringia, which commonly become barren and end in the older schists.

A great number of observations, however, are now at hand, which indicate a variation in the primary mineralogic composition of veins at different depths. A few of them may be mentioned.

In the Himmelsfürst mine at Brand, near Freiberg, the Silberfund Stehende above the 7th level is a typical example of the rich brownspar deposit (carbonspathic lead formation); between the 7th and 9th levels it belongs to a mixture of that type and a pyrite blende lead deposit; below the 9th level it is of the latter class entirely.

In the Junge Hohe Birke mine at the same locality the Prophet Jonas Stehende and other lodes belong, in the upper regions, to the copper deposits; in the deeper zones to the pyritous-blende lead class.

In general it is said that in the deep workings on the Freiberg lodes it has been noted that the amount of pyrite becomes greater, and that of galena less, with increasing depth. Thus in the once rich Peter Stehende of the Alte Hoffnung Gottes mine, and its northeastern continuation, the Einigkeit Morgengang, at a depth of somewhat more than 1,650 ft. (500 m.), the galena is almost entirely replaced by pyrite and blende. Moreover, the galena that does occur has become poorer in silver. The same is true of the Christliche Hilfe Stehende. On the other hand, in the Crown mines, at Freiberg, this increase in pyrite has, indeed, been noticed, but careful assays of selected samples of pure galena show no regular or orderly decrease in the amount of silver in the galena. In a few lodes the laboriously accurate investigations by A. W. Stelzner and F. Kolbeck did, indeed, demonstrate a gradual and constant decrease of the silver content with increasing depth, but in others they showed the contrary. The more accurate results are yet to be published by the last named author.

Concerning the mines in the Upper Harz, F. Klockmann writes[1]: "It is usually stated that with an increasing depth of the mines the sphalerite appears in larger amount" (as compared with galenite). This is confirmed by Zirkler[2]. The silver content of the galenite also decreases slowly in some lodes of that locality with increasing depth. According to Zirkler the silver content calculated for 60% lead decreases as follows in the ores: (1) of the Burgstädt main lode, with 85 feet (26 m.) difference in depth

[1] *Berg- und Hüttenwesen des Oberharzes*, 1895, p. 48.

[2] Zirkler: 'Ueber die Gangverhältnisse der Grube Bergmannstrost bei Clausthal.' *Glückauf*, Essen, 1897, p. 84.

from 0.0889 to 0.0609%; (2) of the middle stringer, with 410 ft. (125 m.) difference in depth, from 0.0865 to 0.0522%; (3) of the Bergmannstrost Hangande stringer, with 866 ft. (261 m.) difference in depth, from 0.0732 to 0.0467%.

Similar changes in depth of silver lead ores are noted by Weed[1] in the mines of Castle Mountain district, and those of the Barker districts, both in Montana. The galena becomes less and less and the zinc and pyrite increase until the latter predominates in depth. The same is true also at Elkhorn at 2,300 ft. in depth.

However, these conclusions seem as yet based on too small a number of examples.

Still more striking differences in depth occur in tin veins: According to B. von Cotta the lodes formerly worked at Seiffen, in the Erzgebirge, are said to have carried in the upper regions mainly tin ore; farther down more copper ore[2]. According to H. Müller[3], however, this was probably due merely to an accidental distribution in the regions in question.

This variation is far more strikingly and conclusively demonstrated by the deep mine workings of the tin ore lodes of Cornwall, as illustrated by the plat of the Dolcoath mine shown on page 214. As another zone of tin ores is found below the copper zone, the change may not be due to depth alone.

Similar phenomena have been observed in manganese veins. According to De Launay[4] and Vogt[5], the manganese deposits occurring in the granites of Romanèche (Saône-et-Loire), in France, carry barytic psilomelane and hematite, together with quartz, barite, a little fluorspar, and traces of calcspar, the psilomelane predominating in the upper region, the hematite in the lower region. De Launay, however, thinks it not impossible that this phenomenon may be of secondary origin.

Secondary Alteration of the Minerals in Veins.

Superficial Alteration of Ore Deposits (Gossan Formation).

The term *superficial alteration* of ore deposits applies to those changes in composition and structure which the ore deposit undergoes above ground-

[1] Walter Harvey Weed: 'The Castle Mountain Mining District,' *Bull.* 139, U. S. G. S. 'The Mines of the Little Belt Mts., 20th *Ann. Rep.* U. S. G. S., Pt. 3, 1900. 'The Elkhorn District, Montana,' 22d *Ann. Rep.*, U. S. G. S., Pt. 2, 1902. See discussion on orderly vertical distribution of ore in veins and theory for it in 'Boulder Hot Springs of Montana,' 21st *Ann. Rep.* U. S. G. S., 1901. p. 249.

[2] B. v. Cotta: 'Erzlagerstätten,' II, p. 23.

[3] H. Müller: 'Die Erzgänge des Freiberger Bergrevieres,' 1901, p. 133.

[4] L. de Launay: 'Compte-Rendu du VIII. Congr. géol. intern.,' 1900, p. 211.

[5] J. H. L. Vogt: 'Problems in the geology of ore deposits,' *Trans.* Amer Inst. Min. Eng., February, 1901, p. 40.

water. The sharp distinction between the conditions above ground-water level, the vadose region, and those below that level, the profound region, was brought out by F. Posepny[1]. The ground-water level in the sense it is used here means the plane, or in cross-sections the height, to which the atmospheric water rises after it has entered the deep regions. A hydrostatic basin which this water fills below that line will in most cases consist of a most complicated and ramified system of fissures, joints, capillary spaces and the gaps between the mineral components or the grains of porous rocks. The elevation of the ground-water line will depend on the relative position of the channels in which the underground water circulates, either towards its exit at the surface of the globe or towards a deeper reservoir separated from the upper porous bed by relatively impervious strata, and thus reached by the water only through a circuitous route.

In general the ground-water level follows the inequalities of the earth's surface, rising with the slope of the land from river valleys and from the sea coast, places where its position coincides nearly with the surface of the ground. In mountains containing numerous wide cavities, as in high limestone regions where the atmospheric water may descend to great depth in the great underground rivers, the ground-water level may lie below 1,640 ft. (500 m.) as reported, for example, by S. F. Emmons from the Tintic district in Utah[2]. In a scientific examination of ore deposits, it is desirable to ascertain as accurately as possible the natural position of the ground-water level, since a knowledge of it is valuable in many respects, both theoretically and practically. Attention must also be directed to alterations of the ground-water level in different geologic epochs.

The paragraphs which follow deal with the chemical changes above ground-water level, not only of veins, but to all ore deposits, since these changes depend not on the form and genesis, but solely on the chemical composition of the unaltered deposits. In the uppermost part of the earth's crust, above the line of permanent underground water, and to some distance below it, most of the metallic minerals of ore deposits undergo alteration through the action of atmospheric air, and lower down by the water which has seeped down and carried, in addition to oxygen, various amounts of carbonic acid, organic acids and perhaps ammonium chloride and hydrogen sulphide. The new minerals, developed in this way, are of course as varied as in the composition of the primary deposit. In general, the sulphide ores will change to oxidic ores of various kinds, carbonates and sulphates, also to native metals, and to chlorine, bromine, and iodine com-

[1] F. Posepny: 'Ueber die Genesis der Erzlagerstätten,' 1895, p. 24.

[2] *Trans.* Am. Inst. Min. Eng., 1900. See also *Tintic Special Folio,* Folio No. 65, U. S. Geol. Survey, 1900.

pounds, phosphates and silicates. The most widely distributed final products of decomposition are brown and red hematite, which occur even where there are no true iron deposits. As the new minerals are very readily recognized by the red or brown coloring of the outcrop, the uppermost and decomposed part of a deposit, especially of a vein, is often described as the iron hat (*eiserne hut* in German, *chapeau de fer* in French), though the English speaking miner calls it gossan, a term originating in Cornwall.

The iron oxides, particularly limonite, form the firm skeleton, as it were, of the gossan, about which the softer or more soluble new minerals accumulate. If the latter are carried away eventually, the outcrop has finally a thoroughly characteristic, porous, cellular, often slag-like structure. Hence such terms as "burnt reefs" for outcrops of this kind. The coloring in such cases is blackish, especially where psilomelane and other manganese ores accompany the limonite, as is often the case.

When comparatively little quartz is present, the ferruginous skeleton remaining may be strongly compressed by lateral pressure and dislocation. In this case the outcrop and gossan of mineral veins are narrower than the unaltered veins below the zone of decomposition. The outcrop may indeed often present an inconspicuous or even barren and uninviting appearance, as for example in the copper veins of Butte, Montana.

The reddish color is not always present. Quite often when copper sulphides predominate in unaltered veins, the gossan is brightly colored, giving rise to the term used by the miners of Spanish South America, *colorados* or *pacos* for the red ores directly at the outcrops; *mulattos* for the deeper zone where simple sulphur compounds usually predominate, and finally *negrillos* for the still deeper dark-colored sulphur compounds of the normal unchanged orebodies.

As the gossan ores yield readily to amalgamation they are called *metales calidos* in Chile, that is, warm ores, because in the presence of iron and an appropriate lye they amalgamate directly with quicksilver with development of heat, which is not the case with sulphidic *metalos frios,* that is to say, the cold ores found at greater depths.

The greater the amount of sulphide ore in the unaltered vein, the greater the amount of secondary material and the more abundant and conspicuous the gossan. It was commonly found that mineral veins devoid of gossan zones rarely repaid the labor of the prospector; hence the much quoted proverb:

> Es thut kein gang so gut,
> Er hat nicht einen Eisern Hut;

or, as they say in Cornwall:

> Gossan rides a high horse.

Climatic conditions have a great influence on the formation of the gossan. In rainless, arid regions, as in South Africa, the Atacama Desert of Chile, the Great Basin Desert of North America, and in the interior of Australia where the aqueous degradation is slight, the destruction of a deposit is due less to rain than to the abrupt change of temperature, resulting from the intense heat of the day, followed by intense radiation. This, combined with the corroding work of the wind, which leaves the heavy metallic particles behind, while carrying away the lighter products of decomposition, results in a gossan especially rich in ore. The metallic compounds are in such regions concentrated to a high degree. Of course, such tracts are not entirely devoid of rain and, moreover, although they are often deprived of it completely for long periods, yet they enjoy at any rate the benefit of dew, so that even there the alteration is perhaps mainly accomplished in the aqueous way. But while elsewhere the soluble newly formed substances are washed off into brooks and rivers, in the arid regions they remain in the gossan, or merely penetrate along cracks and fissures into the similarly decomposed country rock, so as to render the latter also workable in many cases. This is especially true of the newly formed particles of native metal, particularly gold. The rapid decrease in value of gold veins with increase in depth down to the undecomposed zone, is well known. As a result, mining excavations in the zone of oxidation as a rule are much more extensive than at greater depths, where the strong secondary impregnation of the disintegrated rock disappears, or at any rate is greatly diminished[1].

Another peculiarity of the gossan deposits of arid regions is their wealth in metallic chlorides, bromides and iodides, especially of silver. In such arid regions, particularly in enclosed drainage basins, the saline contents of the solutions, arising from the decomposition of a great variety of silicates, are apt to be concentrated in the topmost layer of the solution through the continued strong evaporation of the water. Thus the water in the gold mines of West Australia is often found to be brackish. A sample of water from the Great Boulder mine at Kalgoorlie, according to T. A. Rickard, contained 9% of table salt. Quite generally we find that the countries which contain the so-called 'salt pans' in depressions are also distinguished by a great abundance of chlorine, bromine and iodine compounds in the weathered zone of the rich ore deposits of the region.

Another important factor, according to Emmons[2], is aridity, so that in arid regions the ground-water level lies much deeper than in humid regions.

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes,' *Trans.* Amer. Inst. Min. Eng., 1898, Vol. XXVII, pp. 564-668.

[2] 'Genesis of Ore Deposits,' 9th *Ann. Rep.* Inst. of Min. Eng., p. 438.

Hence the slight rainfall is able to seep down very far before it reaches the masses of water which preserve the original ore of a deposit, and thus this descending water is able to concentrate certain metals throughout the route traversed, as will be explained below. As, moreover, there is no vigorous erosion and denudation in such regions, the same influences may affect parts of a vein to a great depth and for a great length of time.

The minimum development of the gossan is seen in the Northern Hemisphere in the region glaciated in Pleistocene time. In such countries the glacier has almost entirely removed the oxidation zone of the deposits, and no new zone of notable thickness has had time to develop, so that the normal composition of the orebody is encountered directly below the sod. A striking example of this is found in the outcrops of the magnetic iron ore deposits of Sweden, which are almost devoid of a limonite cover, while the zinc-blende deposits of that region are devoid of a calamine gossan.

The chemistry of the gossan[1] varies in character with the complexity of the composition of the original deposit.

We will first consider only those constituents of the gossan for whose development the oxygen or carbonic acid content of seepage water suffices. Even below ground-water level the water still contains some oxygen, but its percentage rapidly decreases with increasing depth, as was proved by Lepsius by means of water samples from drill-holes[2]. Some alterations are therefore possible even below the gossan.

I. *New Substances Developed in the Zone of Oxidation.*

We must begin by recalling that the ore minerals are attacked by the oxygen of the air in very diverse degree, and therefore also with greatly diverse rapidity, as proven by laboratory experiment. Of course in nature the order of succession in this process will frequently vary, because of the influences exerted by the mode of mutual blending of the ores and gangues; the exposed surface of the various substances is the determining factor in the individual case. Thus, according to Emmens[3], the more important sulphides are attacked by decomposition in the following order: (1) marcasite, (2) pyrite, (3) pyrrhotite, (4) chalcopyrite, (5) bornite, (6) millerite, (7) chalcocite, (8) galenite, (9) zinc-blende.

The great tendency to decomposition of marcasite in moist air is well known to all who have to preserve samples in collections. The first stable

[1] J. Roth: 'Allgemeine und chemische Geologie,' Vol. III, Berlin, 1879-1893. R. Brauns: 'Chemische Mineralogie,' Leipzig, 1896.

[2] Ber. d. Deutsch. Chem. Ges., Vol. 18, p. 2487.

[3] Stephen H. Emmens: 'The Chemistry of Gossan,' *The Engineering and Mining Journal*, 1892, p. 582.

products of the weathering of this ore as well as of pyrite and pyrrhotite are iron-vitriol, acid iron sulphates, and sulphuric acid. They are recognized everywhere by the efflorescence upon specimens in the museums and in the corrosion of the attached labels. The same substances are also present in mine water. The sulphate, however, is quickly further oxidized into various ferric sulphates, among others the neutral sulphate. The reaction may be represented by the following equation:

$$2\,FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O.$$

The neutral ferric sulphate thus formed undoubtedly constitutes the principal ingredient of our mine waters (see notes on mine water). It sometimes occurs pure and unmixed, as a syrupy substance in mine cavities; for example in 1896 small outflows of this compound, quickly drying in the air, were seen oozing out of the old stope filling in the Alte Mordgrube near Freiberg. Its occurrence at Coquimbo in Chile is well known (coquimbite). Iron sulphate is extremely common in the mine waters of Butte, Montana, where it sometimes forms stalactites and incrustations in the Silver Bow and other mines.

The neutral ferric sulphate in aqueous solution is believed to play an active part in the further decomposition of pyrite masses, whose first oxidation results in the formation of monosulphides:

$$(1)\quad FeS_2 + Fe_2(SO_4)_3 = 3\,FeSO_4 + 2S.$$
$$(2)\quad 2S + 6Fe_2(SO_4)_3 + 8H_2O = 12FeSO_4 + 8H_2SO_4.$$ [1]

The ferrous sulphate thus formed absorbs in its turn oxygen from the air, and is again changed into neutral ferric sulphate, and may thus again attack monosulphides, until finally all the marcasite, pyrite and pyrrhotite are destroyed. This hypothesis lacks experimental quantitative verification.

Let us consider the alteration of chalcopyrite. The empiric composition $CuFeS_2$ may be written either $Cu_2Fe_2S_4$ or Cu_2S,Fe_2S_3, since one is justified in considering it as a cuprous salt of the acid, hydrated sulphide of iron ($HFeS_2$). Acid iron sulphate may in this case also act as a carrier of oxygen and assist decomposition. Similarly bornite, $3Cu_2S,Fe_2S_3$, and rarely ferrous sulphides, such as iron nickel pyrite, are attacked. The non-ferrous sulphides, on the contrary, are attacked by the solutions, which, in consequence of the decomposition just described, are still rich in acid iron sulphate.

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S.$$
$$PbS + Fe_2(SO_4)_3 = PbSO_4 + 2FeSO_4 + S$$
$$ZnS + Fe_2(SO_4)_3 = ZnSO_4 + 2FeSO_4 + S.$$

But, whatever the process of alteration may be, the final products are always sulphates, most of which are soluble and readily carried off in solution, but sometimes are segregated and redeposited. Reference may

[1] H. N. Stokes: 'On Pyrite and Marcasite,' *Bull.* 186, U. S. Geol. Survey, 1901, p.15.

here be made to the considerable quantities of anglesite (lead sulphate) found in the gossan zone of the Leadville galena deposits and at Tarapaca, and to the fine crystals of anglesite of Monteponi in Sardinia. Although the sulphur in the reactions outlined above is usually oxidized at once into SO_2 and H_2SO_4, yet it sometimes remains in the gossan and is then found alongside of the carbonates and sulphates of lead, etc., as at Leadville and Monteponi (on anglesite). Friable sulphur also occasionally occurs in the cubical cavities left by the dissolution of the pyrite of gold quartz veins and is sometimes associated with native gold (West Australia).

A local accumulation of sulphates is especially formed by dry climate, as in alunite deposits in Colorado, described by Cross and in the deposits of solid melanterite in veins near Whitehall, Mont. Even the readily soluble copper sulphate may then sometimes persist and in rare cases a workable deposit of this substance is known, as in the Bluestone mine, Nevada, and the deposit at Copaquire in the Huatacondo Valley, about 42 miles (70 k.) east of Challacollo in northern Chile. The latter deposits occur, according to Oehmichen[1], in a region, west of the detrital deposits of the Pampa Tamarugal, in which the strongly folded and upraised Mesozoic sediments of the Cordillera are intruded by a granitic rock. For a considerable distance and thickness, near its contact with the sediments, this rock contains stringers and impregnations of blue copper sulphate (chalcanthite) associated with less amounts of malachite, azurite and chrysocolla, besides pyrite, brown hematite and gypsum. A little chalcopyrite seen in rare instances is the only primary ore. Copper salts also occur with molybdenite on fissure walls, and the granite wall rock is strongly decomposed where penetrated by the impregnation. The copper content of the deposit, which is to be extracted by mere leaching with water, has been ascertained to be 2.5 to 3%. Mention should be made of the stalactitic deposits of blue vitriol formed in the workings of the Mountain View and the Silver Bow Mines at Butte, Montana, formed by surface waters seeping down through old stopes filled by low-grade ore.

A great part of the various sulphates formed by weathering are further oxidized; thus the iron sulphate results in the formation of limonite, as in the following equation:

$$12FeSo_4+6O+6H_2O=4Fe_2(SO_4)_3+2Fe_2(OH)_6.$$

Besides oxygen, the carbonic acid contained in the seepage water from above is commonly active. The process is as follows: Since most veins contain calcite or other carbonates, these are dissolved by the carbonated

[1] H. Oehmichen: 'Eine Excursion zur Kupfersulfat-Lagerstätte von Capaquire,' *Zeit. f. Prak. Geol.*, 1902, pp. 147-151.

water. When such solution encounters iron sulphates, the reaction is as follows:

$$Fe_2O_3\ (SO_3)_2 + 2Ca\ CO_3 = 2Ca\ SO_4 + Fe_2O_3 + 2CO_2.$$

Hence, in the zone of decomposition of veins, gypsum and red hematite are not infrequently associated. The process is somewhat different when the carbonate encounters either lead or zinc sulphate.

$$Pb\ SO_4 + Ca\ CO_3 = Pb\ CO_3 + Ca\ SO_4.$$

Thus cerussite or smithsonite, as the case may be, may occur with gypsum. Both minerals will crystallize out at once if their solutions encounter calcium carbonate, which is more easily soluble than the carbonates of lead and zinc. The precipitation of cerussite is still going on in many old mines. Thus, according to A. von Groddeck[1], the levels of the Elizabeth mine at Bleiberg near Commern, when re-opened after an interval of one hundred years, showed coatings of this mineral of the thickness of a finger.

The accumulation of carbonate of zinc (smithsonite) and copper (malachite and azurite) in the gossan is an analogous process. Melaconite, an earthy copper oxide of blackish color, and cuprite (cuprous oxide) usually accompany the copper carbonates.

The formation of cuprite may be represented by the following equation:

$$2Cu\ SO_4 + 2Fe\ SO_4 + H_2O = Cu_2O + Fe_2\ (SO_4)_3 + H_2SO_4.$$

Sometimes the cuprite appears in large kidney-shaped masses, as in the Cobre mine, Santiago, Cuba, and the Luise mine, near Illapel, in Chile. These brilliantly colored secondary copper ores gave rise in Chile and elsewhere in South America to the term *metales de color* for the ores of the gossan in the silver-copper ore lodes of that region.

The sulphuric acid formed in the last equation combines at once with carbonates if they are present, for instance, in the presence of calcite it combines into gypsum. If it remains free, its action upon cuprite may lead to the formation of native copper, as is shown by pseudomorphs of native copper after cuprite : $Cu_2O + H_2SO_4 = CuSO_4 + Cu + H_2O$. The mere presence of ferrous sulphate suffices for this purpose: $3\ Cu_2O + 2FeSO_4 = 4Cu + Fe_2O_3 + 2CuSO_4$.

On the other hand, metallic copper is frequently formed by the reduction of the sulphate by decaying or carbonizing organic substances. Thus native copper was found on the timbers of a drift, in the Rio Tinto mine, dating back to Roman times, on old mine timbers in the copper mines of Kawan Island[2], New Zealand, and elsewhere.

[1] A. von Groddeck: 'Lehre von den Erzlagerstätten,' p. 288.
[2] W. H. Baker: *Zeit. f. Prak. Geol.*, 1901, pp. 37, 367.

In the case of zinc, nickel, cobalt, etc., analogous reactions are not possible, and accordingly these metals are not known in the native conditions in nature.

Native lead is very rare in nature, and conditions favorable for its presence in the gossan occur only in very exceptional cases. It is possible that lead suboxide (Pb_2O) is first formed, which is decomposed by sulphuric acid into Pb and $PbSO_4$; a deoxidation by anhydrous arsenious acid has also been suggested[1]. The association of lead with manganese ores is also remarkable.

Native silver, so often found in gossan and in the deeper regions as well, is manifestly in most cases a secondary product. Masses of pure silver weighing between two and three hundred pounds were found in the gossan of the Planchas de la Plata mines, Sonora, Mexico. It may be formed in many ways, but in most cases the following equation probably represents the usual process:

$$Ag_2\,SO_4 + 2Fe\,SO_4 = 2Ag + Fe_2\,(SO_4)_3.$$

However, its precipitation from solution may be also caused by the reducing action of organic substances, either originally present in the wall rock or secondarily introduced from above. That a reduction really occurs is proved by the casts of fossil fish (*Palaeoniscus*) in the Mansfeld copper shale, some rare specimens of which are known, showing silver plated scales, though ordinarily sulphidic ores have been precipitated on the scaly envelope of these fishes.

In the Freiberg veins native silver has very frequently been deposited along the schistosity planes of the decomposed gneiss wall rock, so that the country rock seems to take part in the reactions, perhaps by means of its ferrous compounds (though there is not a necessary sequence, as actual deposition may take place at some little distance from the location of the reducing agent). At greater depths the secondary production of native silver from argentite may very often be observed[2], and conversely native silver has occasionally been altered back into argentite. Less frequently one observes the reduction of proustite and other rich silver ores to the native metal. Vogt[3] gives illustrations of many specimens from Kongsberg in which the native silver is seen studding crystals of argentite and proustite, in tooth-shaped and moss-shaped aggregates, as if it had grown out of them. Similar instances are not rare elsewhere. In explanation of the process, G. Bischof[4] refers to experiments in which native silver is

[1] S. H. Emmons, *op. cit.*

[2] See what is said later about formation of native silver and the sulphide by reaction between silver sulphate and glance.

[3] J. H. L. Vogt: *Zeit. f. Prak. Geol.*, 1899, p. 113.

[4] G. Bischof: 'Chem. und Phys. Geologie,' Vol. III, 1866, pp. 851-857.

formed when heated water vapor or hot air is passed over silver sulphide. The reaction is as follows:

$$4Ag_2S + 4H_2O = 8Ag + H_2SO_4 + 3H_2S.$$

Sometimes, indeed, a large sliver of silver adheres to a small crystal of argentite whose disproportionate area without any notable decrease of attachment seem to make this explanation inapplicable.

Lastly it is known that native silver can be precipitated from solutions carrying silver sulphate by chalcopyrite, and various other sulphides form argentic sulphide.

After this digression into the reactions taking place below the gossan, let us consider the occurrence of free gold in the true gossan, which is a feature of many deposits even when the deeper zones contain no visible free gold. That the free gold in the gossan is in most cases derived from decomposed auriferous iron pyrites and other sulphides, is beyond doubt. It is more difficult to decide whether the gold was mechanically enclosed in the pyrites or chemically combined. Probably both cases occur in nature. The latter case seems sometimes to be indicated by the distribution of the free gold. Thus W. Mietzschke[1] described grains and crystals of iron pyrite transformed into limonite, with inclusions of native gold. When these limonite pseudomorphs had the form of regular crystals the gold content was segregated in the midst of them as a single grain. When, however, the original pyrite was present as irregular grains, the gold originally distributed uniformly throughout its mass was unable, during the alteration of the pyrite, to reach the center of that space from all sides, and the gold gathered in grains at two or three convenient points. That a part of the gold passes into solution during the decomposition of the ores is proved by the fact that this metal occurs in the mine waters of Australian gold mines. (The real solvent may be a chloride present in small amount in a solution containing $Fe_2(SO_4)_3$. As shown by H. N. Stokes, $Fe_2(SO_4)_3$ dissolves no appreciable amount of gold at 200° C. unless chlorides are present at the same time.)

The gold enrichment of the gossan has already been discussed. If, in the normal vein, native arsenic, arsenious pyrite or other arsenious ores are present, arsenious salts are formed in the gossan, namely arsenolite in the presence of calcareous waters, pharmacolite (hydrated calcium arseniate) frequently also pitticite or iron arsenide sinter, a porodine product at first of syrupy viscosity. The orpiment and realgar of Oravicza in the Banat, and of Allchar in Macedonia, may also be secondary minerals of the gossan.

[1] W. Mietzschke: 'Ueber das Verhalten des Goldes in Pyriten bei deren Verwitterung,' *Berg u. Hutten. Zeit.*, 1896, p. 193.

Smaltite ($CoAs_2$) and other cobalt ores give rise to an efflorescence of erythrite (hydrated cobalt arseniate) occurring in particularly fine crystal groups at Schneeberg in the Erzgebirge.

Nickel ores such as chloanthite ($NiAs_2$) oxidize to annabergite (hydrated nickel arseniate). In this alteration some free arsenious acid will always be formed, which acting on the gangue of brownspar and calcite will cause the precipitation of pharmacolite, haidingerite ($HCaAsO_4$, H_2O), wapplerite ($2H\ [Ca, Mg]\ AsO_4$, $7H_2O$) and roselite, a similar compound of hydrated arseniate of cobalt. In the same way, in the presence of zinc, copper or iron minerals, hydrated arseniates of zinc, copper and iron are formed, or, as shown by Sjögren, if manganese is present, a multitude of the hydrated manganese arseniates are formed[1].

If the original deposit contains stibnite or other antimonious ores, the gossan will show kermesite, senarmontite, more frequently valentinite, stibiconite and cervantite, some native sulphur being usually precipitated at the same time. In the presence of lead ores, lead antimoniates may also be formed, as in several lodes in Chile.

II. New Substances Developed by the Chlorine, Bromine and Iodine Compounds of the Seepage Water.

The frequent presence of small amounts of chlorides in most of the waters circulating at shallow depths in the earth gives rise to chemical changes in the gossan of silver veins and the formation of horn silver (silver chloride = cerargyrite). The process may be represented by the following formula:

$$Ag_2SO_4 + 2Na\,Cl = 2Ag\,Cl + Na_2SO_4.$$

This is all the more likely because, according to G. Bischof[2], some of the analyses of cerargyrite indicate the presence of some sulphuric acid. The real starting point may be represented by argentite and other rich sulphidic silver ores, native silver, silver-bearing galenites, etc. Artificial products also may furnish cerargyrite. G. Bischof mentions old reports according to which silver coins from sunken ships were coated with a crust of silver chloride, and he cites Pallas, who in the saline soil of Siberia found old Tartar silver coins coated with cerargyrite. According to A. Schertel[3], Roman vases of silver obtained in the Hildesheim find of 1868 showed an outer crust of silver chloride ($AgCl$), above a layer of silver semichloride

[1] G. Brauns: 'Chem. Mineralogie,' 1896, p. 370.

[2] G. Bischof: 'Geologie,' 1866, Vol. III, p. 808.

[3] A. Schertel: 'Chemische Veränderungen am Hildesheimer Silberfunde,' *Jour. f. Prak. Chemie.*, 1871, Vol. 3, p. 317.

(Ag_2Cl). Between the latter and the unattacked metal, gold particles had concentrated, since the silver of the vases contained 2.7% gold.

Since native silver is so frequently found alongside of cerargyrite in nature, it is possible that the former has often been formed from the latter.

Cerargyrite sometimes appears in the form of concretions, or grains which may be detached from their genetic connections. Thus in the Apollyon Valley, and at Turnamoota in the Barrier range of New South Wales, on the surface near the outcrop of silver veins, concretions of this kind were found weighing several pounds, and containing, according to C. Watt, 72.23% of silver chloride.

In the presence of alkaline iodides and bromides in the seepage water, iodite (AgI), embolite (AgClBr), and the rarer bromite, are formed in the gossan. All these haloid compounds of silver, as well as native silver, have occasionally journeyed downward through the gossan and concentrated below. Thus at Broken Hill, within the gossan, whose upper part was quite barren, the famous horizons of immensely rich secondary silver ore were found only at a depth of 100 ft. (30 m.) In like manner the free milling argentiferous *pacos* ores of the Bolivian deposits only occur in the deeper zones of the gossan immediately above the sulphides.

According to F. A. Moesta[1] the Chilean silver veins show a succession of hornsilver ores in the gossan. The silver chloride is at the top, iodo-chloro-bromide of silver below, and still lower the pure silver iodide; below the chloride zone native silver, as well as argentite, polybasite and proustite, occur.

A similar explanation may be given for the occurrence of several other chemically related compounds in the uppermost parts of veins, viz.: atacamite ($CuCl_2$, $3CuO_2H_2$), calomel (HgCl), phosgenite ($Pb_2Cl_2CO_3$), as well as percylite (PbCl[OH].CuCl[OH]), and others.

In certain cases it seems proven that such chlorine compounds may form under the direct action of sea water on outcropping ores. Thus for example, B. R. Brauns[2] mentions the formation of laurionite [PbCl(OH)] and fiedlerite (a lead oxychloride of complicated compositions) through the action of sea water on the lead slag of Laurion, which is 2,000 years old. Moesta[3] even goes so far as to affirm that the rich cerargyrite of the Chañarcillo and other Chilean deposits was produced by the salt of sea water, which, according to him, stood at one time above the outcrops. Other authors have expressed similar views concerning hornsilver deposits, or

[1] F. A. Moesta: 'Ueber das Vorkommen der Chlor.- Brom- und Jodverb. des Silbers,' Marburg, 1870.

[2] R. Brauns: 'Chemische Mineralogie,' Leipzig, 1896, p. 367.

[3] *Op. cit.*

have at any rate assumed saline, marine sediments from earlier times in the vicinity of such finds, or, like C. Ochsenius[1], inferred that the 'mother lye' flowing out of upraised saline lagoons penetrated into the ore deposit from above. In individual cases this explanation may be appropriate. F. Sandberger[2] tried to support this hypothesis, especially by reference to hauntajayite ($AgCl+20NaCl$) which was found in the San Simon mine in the Cerro de Huantajaya in Peru, associated with silver chloride, silver chlorobromide, and atacamite.

On the other hand, it must be pointed out that considerable quantities of cerargyrite have also been found occasionally in the rocks of central Germany. At Annaberg, in the Erzgebirge of Saxony, for instance, in the 16th century, cerargyrite was found in the Himmlisch Heer mine in masses so large, pure and soft that figures are said to have been carved from it, since it could be cut 'like soap.' According to documentary evidence pure samples of it, alleged to have weighed fifty pounds, were furnished to the Natural History Cabinet of Dresden[3]. Cerargyrite in compact bodies was found on the Segen Gottes vein at Gersdorf as late as 1854, and about twenty-five years ago in the works of the Sanct Georg mine at Schneeberg, once so rich in silver, but flooded since 1550. At Gottes Geschick on the Graul, near Schwartzenberg, embolite occurred, though only rarely[4]. Now, as in the Erzgebirge it is not possible to imagine either an overflow by the sea, or a seepage of a residual lye from evaporated brines, it seems to us that with the exception of perhaps a few individual cases the theory above set forth is inapplicable to the other cerargyrite occurrences. If a rule may be formulated, as seems to be possible, it is that the drier a country is, the greater will be the amount of cerargyrite in the gossan of the veins. It is probable that the haloid compounds, formed in very small amounts by the weathering of rocks, were concentrated in the upper strata of the soil solely as a result of the hot climate and the enclosed condition of those regions. The blowing of saline dust by the wind, away from the coast or from saline lakes, may co-operate to produce this effect. The fact that in this process the metallic iodine and bromide compounds, which otherwise are relatively so much rarer, occur in considerable quantity alongside of the chloride minerals, has been appropriately explained by B. Kosmann[5] as a result of the greater insolubility of the former. The smaller quantities of alkaline

[1] C. Ochsenius: 'Die Bildung des Natronsalpeters aus Mutterlaugensalzen,' Stuttgart, 1887, p. 51.

[2] *N. Jahrb. f. Min.*, 1874, p. 174.

[3] H. Müller: 'Das Annaberger Bergrevier,' Leipzig, 1894, p. 92. A. Frenzel: 'Mineral. Lexikon für das Königreich Sachsen,' Leipzig, 1874, p. 167.

[4] M. Websky: 'Silberhornerz im Sct. Georgs Schacht zu Schneeberg,' Z. d. D. G. G., 1881, Vol. XXXIII, p. 703.

[5] B. Kosmann: 'Ueber die Bildung haloïdischer Erze.,' Leopoldina, XXX, 1894, p. 1.

iodides and bromides in the seepage water were always the first to combine as metallic haloids by the reaction with the ore minerals; the alkaline chlorides were then formed in turn. The succession of the cerargyrite zones, as cited above, after Moesta, does not, it is true, harmonize with this view.

A thorough investigation of the question of the origin of cerargyrite, taking into account both geological and chemical facts, is certainly a problem of very great scientific interest that still awaits a solution.

For the alterations and migrations of material in the gossan of gold veins, the presence of chlorine compounds in the seepage water has much significance. Since sulphuric acid is formed by the decomposition of the pyrites, as already shown, and since, moreover, psilomelane is common in the gossan formations, favorable conditions prevail for the development of chlorine as the most active solvent of gold. The gold may be precipitated again by undecomposed pyrites, which may lead to the development of zones especially rich in gold between the oxide and sulphide zones of the veins. Percy demonstrated the possibility of these processes by experiments[1].

III. New Compounds Formed by Combination with Phosphoric Acid.

The real source of the phosphoric acid in the gossan is probably in most cases the apatite of the country rock. When leached by water containing CO_2 it yields a solution of $Ca_3(PO_4)_2$, which decomposes on encountering gypsum and precipitates the metallic phosphates in question. The phosphoric acid in the solutions may also arise from decaying animal substances. In both cases pyromorphite, liebenthenite, phospho-chalcite, hopëite, cacoxenite, strengite, dufrenite and beraunite may be formed in the gossan.

IV. New Minerals Formed by the Liberation of Silicic Acid.

The decomposition of the feldspars of the country rock, by sericitization and other similar processes, sets free silicic acid, which may be reprecipitated as quartz, chalcedony, hornstone or opal, or may form compounds with the metals. A mineral especially common in the gossan of copper-bearing lodes is chrysocalla ($CuSiO_3$, $2H_2O$), and silicate of zinc frequently occurs in many zinc-blende deposits. Blue allophane ($Al_2SiO_5+Cu_2O+H_2O$) is rarer; it occurs in the Blaue Stolln at Zuckmantel in Silesia, being derived from the decomposition of copper-bearing pyrites. Ore deposits often hold included fragments of country rock rich in feldspar. In the gossan these

[1] T. A. Rickard: 'Formation of Bonanzas in the Upper Portions of Gold Veins,' *Trans.* Am. Inst. Min. Eng., February, 1901.

are often completely altered to kaolin, which may be strongly impregnated with silver chloride, as at Broken Hill.

V. Removal of Dissolved Substances.

Strong proof that all of the above mentioned decomposition processes prevail generally in the weathered outcrops of mineral veins, and that a very large part of the new compounds thus formed are not precipitated in the gossan, but are carried off in aqueous solution, is furnished by the analyses of mine waters[1].

I. The following analysis (a) by A. Frenzel represents a mine water of the Rothschönberger Stolln, near Freiberg, which gushed forth in 1877 from the Komm Sieg mit Freunden Spatgang; (b) is a second mine water from the same locality which gushed forth from the Hilfe des Herrn Stehende Gang; (c) is a third mine water in the same mine which also gushed forth from a vein.

The waters in question contained per liter:

	a.	b.	c.	
Sulphuric acid	0.2334	0.2224	0.2159	gram.
Silicic acid	0.0088	0.0080	0.0021	"
Alumina	0.0028	0.0007	0.0028	"
Ferric oxide	0.0067	0.0090	0.0068	"
Manganic oxide	0.0027	0.0059	0.0083	"
Zinc oxide	0.0235	0.0059	0.0035	"
Cobalt and nickel oxide	Trace.	Trace.	Trace.	
Chlorine	Trace.	Trace.	Trace.	
Lime	0.1485	0.1014	0.1270	"
Magnesia	0.0284	0.0247	0.0217	"
Insoluble residue	0.0175	0.0158	0.0210	"
	0.4723	0.3938	0.491	"

II. Chemical composition of the mine water of the Rothschönberger Stolln at its point of discharge in the Triebisch Valley. The average discharge is 500 liters per second. Analyses made by A. Frenzel in 1883. One liter contained:

Lime	65.0	milligrams.
Magnesia	24.9	"
Ferrous oxide	9.5	"
Zinc oxide	11.1	"
Chlorine	12.4	"
Silicic acid	18.0	"
Sulphuric acid	104.0	"
Total	249.9	"

From that it is seen that the amount of zinc oxide which is carried off by this water from the Freiberg mines averages 479 kilograms a day, or in a year 175,024 kilograms.

[1] H. Müller: 'Beiträge zur Kenntniss der Mineralquellen und Stollenwässe Freiberger Gruben,' *Jahrb.* f. d. B. u. H. im Königr. Sachsen, 1885.

In renovating the old workings of the Beihilfe Erbstolln on the Halsbrücker Spatgang, which had been flooded for 135 years, the walls of the levels and other workings were found to be covered with a black efflorescent coating one centimeter thick. An analysis of this crust made by H. Schulze showed it to have the following composition:

Manganese peroxide	44.78	per cent.
Oxygen	8.43	"
Ferrous oxide	7.78	"
Cobalt oxide	1.36	"
Zinc oxide	6.08	"
Cadmium oxide	0.19	"
Lead oxide	3.45	"
Copper oxide	3.20	"
Sulphuric acid	0.82	"
Water	19.84	"
Residue insoluble in acids	3.55	"
Total	99.48	"

The insoluble residue consisted of mica scales and quartz splinters from the country rock, the usual Freiberg gneiss.

The manner in which gold passes into solution during the decomposition processes forming the gossan is discussed on page 372 and also in the section on gold placers.

THE ZONE OF ENRICHMENT BY RICH SECONDARY SULPHIDES.

Weed discriminates the following zones in ore deposits[1]:

(1) The zone of weathering; a zone above groundwater level, made up principally of oxides, carbonates, chlorides, etc., which may also carry rich secondary sulphides;

(2) The zone of enrichment; a transition zone at and below groundwater level, characterized by rich sulphides of silver, copper, lead and zinc, containing only subordinate oxidic ores;

(3) The zone of unaltered ores; the normal unaltered sulphides.

The poorer sulphides of (3) are altered to rich sulphides of (2) by reactions with the oxidic compounds contributed from above in solution.

These reactions may be of very diverse nature.

The following equations[2] indicate the nature of the chemical changes possible when copper sulphates come into contact with pyrite:

[1] The translator has replaced the original text by new material, assuming responsibility therefor.

[2] This synopsis of the chemical reactions involved in secondary enrichment has been kindly written by Dr. E. S. Sullivan, of the Chemical Laboratory of the U. S. Geological Survey. The equations are actual, not theoretical ones. W. H. W.

(1) Direct precipitation of sulphides:

(a) $CuSO_4 + H_2S = CuS + H_2SO_4$.
(b) $Cu_2SO_4 + H_2S = Cu_2S + H_2SO_4$.

(2) Reduction of $Cu^{\cdot\cdot}$ to $Cu^{\cdot}$ by H_2S:

(c) $2\,Cu_2SO_4 + 2\,H_2S = Cu_2S + S + H_2SO_4$[1].

The sulphur may be further oxidized to H_2SO_4 with reduction of a greater amount of $Cu^{\cdot\cdot}$:

(d) $6\,CuSO_4 + S + 4\,H_2O = 3\,Cu_2SO_4 + H_2SO_4$[2].

(3) Reduction of $Fe^{\cdot\cdot\cdot}$ by $Cu^{\cdot}$:

(e) $Fe_2(SO_4)_3 + Cu_2SO_4 = 2\,FeSO_4 + 2\,CuSO_4$[3].

This reaction is reversed on heating to about 200°C.

(f) $2\,FeSO_4 + 2\,CuSO_4 = Cu_2SO_4 + Fe_2(SO_4)_3$[4].

(4) Splitting up of cuprous compounds into cupric and metallic copper:

(g) $Cu_2SO_4 = Cu + CuSO_4$[5]

The sulphur of metallic sulphides, as Fe_2S_3, is in the same form of combination (the same ion, S″) as in hydrogen sulphide, and in many respects behaves similarly. Polysulphide sulphur is, as a rule, loosely combined, and may be expected to act like free sulphur. Pyrite being regarded as ferric polysulphide, $Fe_2S_3S\,(={}_2FeS_2)$, to represent its behavior in the above reactions Fe_2S_3 is substituted for H_2S, and the residual S for free sulphur, ferric or ferrous sulphate becoming an additional product.

In equation (a) for instance:

(h) $3\,CuSO_4 + Fe_2S_3S = 3\,CuS + Fe_2(SO_4)_3 + S$.

The ferric sulphate would be easily reduced by H_2S or S, the sulphur becoming free sulphur or sulphuric acid.

(i) $Fe_2(SO_4)_3 + H_2S = 2\,FeSO_4 + S + H_2SO_4$.
(k) $3\,Fe_2(SO_4)_3 + S + 4\,H_2O = 6\,FeSO_4 + 4\,H_2SO_4$[6].

This is sufficient to indicate also the behavior of pyrite in reactions (b), (c) and (d), the products being the same as in those equations with addition of ferric or ferrous sulphate.

Chalcopyrite, $Cu_2S,Fe_2S_3\,(=2\ CuFeS_2)$, and bornite, $3\ Cu_2S,Fe_2S_3\,(=2\ Cu_3FeS_3)$, combinations of cuprous sulphide and ferric sulphide, would, on entering into reaction, behave similarly.

[1] Branner: *Chem. News*, 1896, LXXIV, p. 99. Also *Compt. rend.*, 1884, XCVIII, p. 1492.
[2] Stokes: 'Pyrite and Marcasite,' *Bull.* No. 186, U. S. Geol. Survey, 1901, p. 44.
[3] Prescott and Johnson: 'Qualitative Analysis,' p. 159.
[4] Stokes, *op. cit.*
[5] Luther: *Zeit. phys. Chem.*, 1901, XXXVI, p. 392.
[6] 'Gmelin-Kraut,' Vol. 1, pt. 2, p. 219.

We have thus the possibility of a variety of changes, many of them conflicting. Which would preponderate, and what the final products would be where several are in simultaneous operation, depends on relative concentration, on temperature, and even on the pressure under which the substances find themselves[1]. One case involving a number of these reactions has been worked out, with careful control of physical conditions, by Dr. H. N. Stokes, as follows.[2]

"Copper sulphate acts in part according to the following equation: $5\ FeS_2+14\ CuSO_4+12\ H_2O=7\ Cu_22S+5\ FeSO_4+9\ H_2SO_4+3\ H_2SO_4$, the last H_2SO_4 being formed by oxidation of the sulphur of the FeS_2. The formation of H_2SO_4 was proved by quantitative analysis, both at 100 and 180°. The reaction is not as simple as thus expressed, for some CuS is formed less at 100 than at 180°. Cuprous sulphate, Cu_2SO_4, also plays a part in the reaction."

Lead salts are transposed into the least soluble of the lead compounds, galenite, by the sulphides of other metals, especially by those sulphides, such as blende, more soluble in water than galenite:

$$PbSO_4+FeS=PbS+FeSO_4.$$
$$PbCO_3+FeS=PbS+FeCO_3.$$

or,

$$PbSO_4+ZnS=PbS+ZnSO_4.$$
$$PbCO_3+ZnS=PbS+ZnCO_3.$$

Pyrite (Fe_2S_3S) might be expected to act similarly, its residual sulphur being deposited as such or oxidized, perhaps by $Fe^{\cdots}$ to H_2SO_4. Zinc sulphide may be formed thus:

$$ZnSO_4+H_2S=ZnS+H_2SO_4.$$

The action of pyrite on zinc compounds in alkaline solution was investigated quantitatively by Stokes, and found to result in ZnS, as follows:

$$14\ ZnCO_3+8\ FeS_2+NaCO_3=14\ ZnS+4\ Fe_2O_3+Na_2S_2O_3+15\ CO_2.$$ [3]

Thus a regeneration of the galenite decomposed in the uppermost lode regions has been effected at a somewhat greater depth by the descending currents.

A deposition of secondary chalcopyrite, or, under certain circumstances, a first segregation of rich copper sulphides, may be caused in deposits of

[1] Any attempt to sum up such reactions in one chemical equation takes upon itself to decide which one or more of several conflicting changes will take place to the complete or partial exclusion of the others; this is not justified unless the facts in the case have been ascertained by quantitative analysis of the products formed, and even then such an equation is but an approximate representation of what actually takes place.

[2] MS. H. N. Stokes.

[3] MS. H. N. Stokes.

primary cupriferous pyrite by solutions of $CuSO_4$ entering from above, and may be expressed as follows:

Formation of Chalcopyrite and Bornite.

(1) Reduction of $CuSO_4$ to Cu_2SO_4 by sulphur of FeS_2.
(2) Transposition of Cu_2SO_4 to Cu_2S by Fe_2S_3.
(3) Union of Cu_2S and Fe_2S_3.
Incidental products: H_2SO_4; $Fe_2(SO_4)_3$; $Fe^{\cdot\cdot\cdot}$ reduced by S to $Fe^{\cdot\cdot}$, sulphur oxidized to H_2SO_4.

Cu_2SO_4 decomposes in part into Cu and $CuSO_4$, accounting for Cu associated with bornite and chalcocite.

Chalcocite may also be produced in various ways within the descending currents: Through the reaction of copper sulphates on pyrite:

$$14\ CuSO_4 + 5\ FeS_2 + 12\ H_2O = 7\ Cu_2S + 5\ FeSO_4 + 9H_2\ SO_4 + 3H_2SO_4.$$

This last H_2SO_4 is formed by oxidation of the sulphur of the FeS_2.[1]

Through the reaction of copper sulphates on chalcopyrite or bornite, a combination of such changes as those expressed in equations h, d, and b preceding.

As examples of these alterations we refer to the chalcopyrite nodules of the Monte Catini mentioned on page 48, with their envelope of bornite and chalcocite, associated with native copper. Also the cupriferous portions of the lodes of Butte near ground-water level, as well as the concentration of rich copper sulphides from copper-bearing pyrites in certain deposits in Arizona.[2]

In similar manner, in veins carrying slightly argentiferous sulphides, the silver salts formed by weathering may migrate downward, and the silver be precipitated at a lower level by contact with undecomposed sulphides of the veins as rich silver sulphides.

The reaction is as follows:

$$Cu_2S + 2\ Ag_2SO_4 = Ag_2S + 2\ Ag + 2\ CuSO_4.^{3}$$

This reaction explains the frequent association of native silver and argentite in mines.

$$Cu_2S + 4\ AgCl = Ag_2S + 2Ag + 2CuCl_2.$$

The principle of secondary enrichment of copper ores has long been known and was definitely formulated by Emmons[4] in 1897, while a general application of this principle to gold, silver and other metallic deposits was

[1] MS. of H. N. Stokes: See note on the equation on previous page.

[2] R. A. Penrose: 'The Superficial Alteration of Ore-Deposits.' *Journ. of Geol.*, II, 1894, pp. 306–308. Jas. Douglas: 'The Copper Queen Mine, Arizona,' *Trans.* Am. Inst. Min. Eng., February, 1899.

[3] Schneider: *Pogg Annal.*, 1874, Vol. CLII, p. 471.

[4] U. S. Geol. Survey, Folio 39, Butte, Mont.

given by Weed in 1898[1] and 1899[2], and independently by Emmons[3] and Van Hise[4] in 1900. The latter had long since explained the formation of the Lake Superior iron ores as being due to a similar process. (W. H. W.)

L. De Launay studied the processes of weathering in detail and emphasizes the removal of the more readily soluble substances. He did not, however, recognize any changes below water level or the reactions between descending solutions and primary sulphides.

The formation of rich secondary sulphide ores by reactions between primary ore and later uprising deep waters, according to the theory of W. H. Weed, is not a gossan phenomenon and is discussed elsewhere.

The expression, "zone of rich sulphides," must not be understood in the sense of a definite, sharply defined zone. Lesser and later fissures permit a descent of the seepage water from above to the deeper portions of the deposit, with accompanying leaching in some parts and enrichment in others.

THE DISTRIBUTION OF ORE WITHIN THE VEINS.

Only very rarely do we find the ore minerals of a vein uniformly distributed through the vein filling. This filling consists chiefly of various gangue minerals, quartz, calcite, brownspar, rhodochrosite, fluorite, etc., as well as of fragments of the country rock. A rare case occurs at the rich Smuggler vein of Telluride, Colorado, in which for a distance of nearly three-quarters of a mile (1 km.) there was not a single spot that could not be profitably worked. As a rule the pay ore is concentrated in parts of the vein known as bonanzas, pay streaks, shoots, pipes, chambers, bunches, and nests, as the workable portions are variously called. The poor or lean portions are known simply as barren places, or have received no distinctive name[5].

The determination of the form and distribution of the orebodies of a vein, horizontally and vertically, and the relations between these occurrences and the general and structural geologic conditions of the vein and its enclosing rocks is not only of great practical value, but also of the highest

[1] 'Secondary Enrichment of Veins, Geol. of Little Belt Mts.' 20th *Ann. Rep.* U. S. Geol. Survey, 1898-9, p. 412. 'Kemp Ore Deposits,' p. 38.

[2] 'Geol. Society America Program and Abstracts of Papers,' November, 1899, *Science*, November 20, 1899. 'Enrichment of Mineral Veins by Later Metallic Sulphides,' *The Engineering and Mining Journal*, December 30, 1899. *Bull.* Geo. Soc. Am., 1900, Vol. II, pp. 179-206.

[3] W. H. Weed: 'Enrichment of Gold and Silver Veins.' 'Genesis of Ore Deposits,' p. 473. S. F. Emmons: *Idem*, p. 433.

[4] C. H. Van Hise: *Idem*, p. 282.

[5] When pay ore occurs the vein is said to be rich; the transition from a barren to a rich portion is called enrichment (Veredelung), and conversely the passage from a rich to a barren region is called impoverishment (Vertaubung).

scientific interest. For a long time the investigators of ore deposits have endeavored to discover, if possible, general laws governing the distribution of the orebodies in veins, laws which might in turn prove useful in mining practice. However, the results thus far obtained have only a local application. In the following sections, pp. 382 to 395, some general causes of the origin of rich orebodies will be discussed.

The unequal distribution of orebodies appears best in a well executed longitudinal section along the vein, that is to say, a section parallel to the strike and dip. This should show the shafts, horizontal drifts, and the actually developed and worked portions of the veins, besides the intersections of other veins, and if possible the changes in the nature of the country rock. Compare Figures 187 and 188.

A very frequent phenomenon is the presence of orebodies dipping diagonally across the vein, the so-called pitching ore shoots (Erzfalle or Adelvorschube) (see for example Fig. 175); these narrow orebodies, whose longer diameter coincides with the line of dip, the so-called ore pipes, are especially common in gold veins[1] (see, for example, Fig. 181), while the bunches are masses which have a very limited extent.

The word, "Adelvorschube" (ore shoot), was first used only in the mines of the Heinzenberg and Kelinkogl, and was introduced in science by J. Trinker[2]. In the Kleinkogl deposits in northern Tyrol, containing copper and silver ores, he proved that the different bonanzas of the successive lodes follow one another in accordance with a certain law, all being inclined at about 30° to the horizon in the direction from south to north. This behavior he calls a general enrichment (Generellen Adelsvorschube).

In America Clayton's law has proven locally applicable in many mineral districts in the western United States. According to this the ore shoots pitch to the right in looking down a lode along its dip. The detailed studies by Lindgren and others fail to confirm the general application of this.

The word 'bonanza' is much used for rich orebodies, especially in silver mines. In Mexico it means merely payable ore; in common usage it means a body of very rich ore. The bonanzas of the Comstock Lode are especially famous.

For the most part the workable orebodies represent only a small part of the entire lode. Thus Freiherr von Beust, in 1859, estimated the pay streak to constitute 20% of the area of the vein in longitudinal section of the workable Freiberg lodes. Later statistics (1871) gave only 15 per cent.

[1] E. Skewes: 'The Ore-Shoots of Cripple Creek.' *Trans.* Amer. Inst. Min. Eng., 1897, XXVI, p. 553 *et seq.*

[2] J. Trinker: 'Der Adelsvorschub am Heinzenberge und am Kleinkogl.' *Jahrb.* d. k. k. geol. Reichsanst., 1850, Vol. I, p. 213 *et seq.*

Different conditions obtain when the enrichments of lodes are due not to a higher grade of ore, but to an increased amount of ore, in consequence of a widening of the lode fissure. We may refer to what has been said on page 148. In this sense, in the veins which are fault fissures, those sections would always be the richest in which there is a great variation of dip, because in such cases the displacement of the walls develops the largest lode spaces. This idea was advanced in somewhat similar terms by W. J. Henwood[1].

In the case of a well-banded vein filling, much will depend on whether the richest crusts are the latest or the youngest. If they are the youngest they will often be met only at points where the lode is greatly expanded, whereas, they will be commonly absent where it is much contracted.

Influence of the Country Rock on the Richness of Lodes.

For several centuries the German miners have been acquainted with the undeniable influence of the country rock on the ore content of mineral veins. They spoke of an "obliging, mannerly rock" (einen artigen, hefflichen Gebirge), as compared with a "wild and unfavorable" (wilden und unartigen). The first detailed scientific investigation upon this subject was begun by the Freiberg geologists, H. Müller and B. von Cotta. We will first note a number of examples in which a different country rock is accompanied by a difference in ore, and afterward discuss the real causes of this phenomenon, so far as known.

A very detailed study of this subject, applied to the Freiberg area, was published by H. Müller[2] as early as 1850, from which we extract the following:

The most striking fact in the Freiberg lodes is the unfavorable influence of the mica schist as compared to the favorable influence of the gneiss. This is all the more unpleasantly conspicuous because the very richest, highest grade veins of the district occur where such mica schist intercalations occur within the gneiss, so that the workable ore is restricted to a limited part of the field. The most important veins of the north of the town furnish numerous illustrations. Thus the great bonanza of the Peter Stehende vein ends northward where the vein passes from gneiss into mica schist, and the rich vein filling of the Wilhelm Morgengang and the Friedrich Flache veins of the same locality changes to barren gangue in the mica schist.

The veins of Alte Hoffung Gottes also run southwestward into mica

[1] W. J. Henwood: 'Metalliferous Deposits of Cornwall and Devon.' *Trans.* Roy. Geol. Soc. of Cornwall, V.

[2] H. Müller: 'Erzlagerstätten bei Freiberg.' Cotta's Gangstudien, 1850, Vol. I, pp. 209–248.

schist. While in the gneiss they are 0.6 to 2.2 feet (0.2 to 0.8 m.) thick, and consist of quartz, brownspar and rhodochrosite, containing pyrite, sphalerite, galena and, not infrequently, rich silver ores. In the mica schist these veins narrow to a thickness of a few inches, the gangue and ore

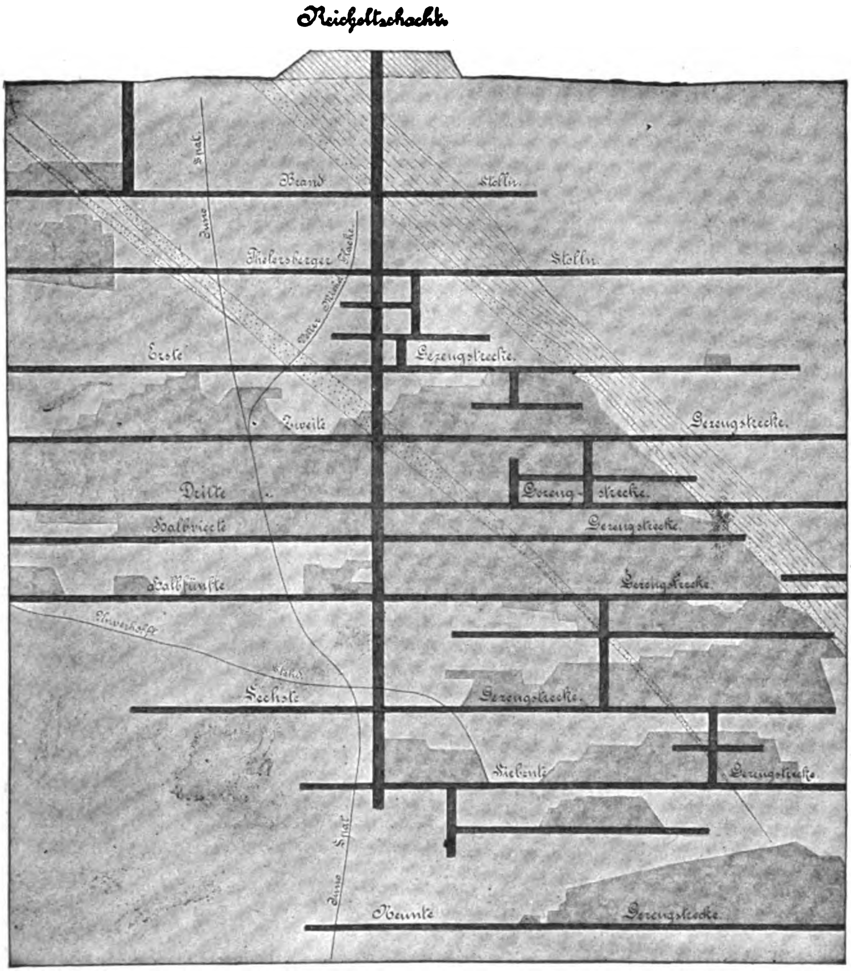


Fig. 187.—Horizontal section of the Jupiter vein in Himmelsfürst mine. (Plate of the Royal Mining Bureau.)

minerals are lacking, and the filling consists almost solely of decomposed fragments of the country rock, friction breccia and gouge.

The same phenomena is repeated in the Himmelsfürst mine at Brand in the rich lead veins (carbonspathic lead formation). As is shown distinctly by the accompanying section through the Reichelt shaft of the Jupiter Stehende (Fig. 187), prepared from the official mine maps, the rich ore streaks are found in the so-called Himmelsfürst gneiss, a normal biotite gneiss underlying the mica schists. In the mica schist the veins grow so poor that no excavations are recorded. A similar distribution of ore is found in several other lodes of this district. On the other side of the bands of mica schist, rich ores again appear in some veins, as, for example, in the Wiedergefunden Glück Stehende. In the mica schist itself, however, pay streaks were found along the intersections with other veins, as, for example, in the Lade des Bundes Flachen, along the intersection with the Johannes Stehende.

To explain these conditions in the Himmelsfürst mine the hypothesis of "an enrichment of the veins just before they pass into the mica schist, particularly along the lower gneiss-schist contact," is even more appropriate than the assumption "of an impoverishment of the ore lodes in the mica schist," since the value of the ore along the under wall of the mica schist far exceeds that usually found in the vein when encased in normal biotite gneiss.

The following statistics prove the great wealth of this zone: In the Silberfund Stehende, from 1857 to 1879, the ores from 47,366 square meters of lode surface, weighing 7,940 metric tons, gave an output of 4,426,784 marks ($1,107,192); in the Kalb Stehende the ores from 34,017 square meters lode surface, weighing 6,194 metric tons, gave 2,199,874 marks ($550,000), so that in the first case the square meter yielded on an average 93 marks, in the latter 65 marks.

To explain this "contact enrichment" (H. Müller), one must also consider the possibility of a checking or stagnation of the rising solutions caused by the imperfect fissuring of the mica schist.

A closely analogous phenomenon exists in silver-quartz veins, as shown by longitudinal sections of several lodes of the Segen Gottes Erbstolln at Gersdorf, near Rosswein, as well as in the Friedrich Flachen, of the barytic lead veins. In all these veins extensive orebodies occur where the veins are in the gabbro and granulite. The orebodies attain their greatest thickness and value at the immediate contact plane between the phyllite (mica clay slate) and the gabbro and granulite faulted against it; the ore stops where the veins pass into the phyllite hanging-wall.[1]

We may mention a few examples from other regions of the influence of the country rock on veins. The number might be considerably increased from the old descriptions by B. von Cotta[2].

[1] H. Müller: 'Die Erzgänge des Freiberger Bergrevieres,' 1901, p. 296.
[2] B. von Cotta: 'Erzlagerstätten,' I, 2d ed., 1859, p. 133, *et seq.*

In the barite veins of Schweina and Kamsdorf, in the Thüringer Wald (see page 227), at Riechelsdorf, in Hesse, where the veins traverse the bituminous copper shales, they contain pay streaks of cobalt, nickel and copper ores, while in overlying beds of the Zechstein formation and in the rocks beneath the copper schist the veins are barren.

At Pribram the veins are profitable in the Cambrian quarzitic sandstone, but not in the clay slate adjoining on the northwest (see Fig. 158 and 159). This is, however, probably due more to the influence of the clay fissure mentioned on page 143 than to the clay slate in itself.

In Cumberland the lead veins, according to Dufrenoy[1] and others, traverse Carboniferous limestone, with interbedded sandstone and clay slate. While in the limestone the veins are thick and workable; in the sandstone and slate they break up into unprofitable stringers. Similar conditions are observed in Derbyshire, where the lodes become poor and divide into stringers as soon as they enter the intrusive sheets and dikes of diabase amygdaloid (locally called toadstone).

The influence of fahlbands of the schists upon the Kongsberg silver ore lodes has already been mentioned on page 275.

The copper lodes of Butte, Montana, according to W. H. Weed[2], are ore-bearing in the basic granite and are low grade or barren in the aplite.

An interesting example of the enrichment of gold-bearing lodes in passing through a particular rock occurs in the Ballarat gold field of Victoria, Australia[3]. The quartz veins traverse a series of steeply upturned Silurian slates, but only carry pay ore where they cross extremely thin but persistent beds (½ inch to 6 inches thick) of a heavily pyritized bituminous shale. These intersections are exceedingly rich in gold, and, in mining these, thin beds known as indicators are followed. The indicators themselves are barren[4]. See Fig. 187*a* and 187*b*.

It should, however, be noted that there are districts in which the distribution of the ore in veins is apparently independent of the character of the country rock. An exceptional case described by Wittelsbach[5] occurs in the Santa Elena and La Carolina mineral districts, near the Linares lead region. The Paleozoic slates and intruded granite masses are cut by

[1] Dufrenoy, E. de Beaumont, Coste and Perdonnet: 'Voyage métallurgique en Angleterre.' Paris, 1837 and 1839.

[2] W. H. Weed: 'Influence of Country Rock on Mineral Veins,' *Trans.* Am. Inst. Min. Eng., November, 1901.

[3] T. A. Rickard: 'The Indicator Vein, Ballarat, Australia.' *Trans.* Am. Inst. Min. Eng., August, 1900. With bibliography.

[4] See 'Characteristics of Gold Quartz Veins of Victoria,' W. Lindgren, *The Engineering and Mining Journal*, March 9, 1905. Also Weed, *op. cit.*

[5] A. O. Wittelsbach: 'Fragen und Anregungen,' etc. *Zeit. f. Prak. Geol.*, 1897, p. 5.

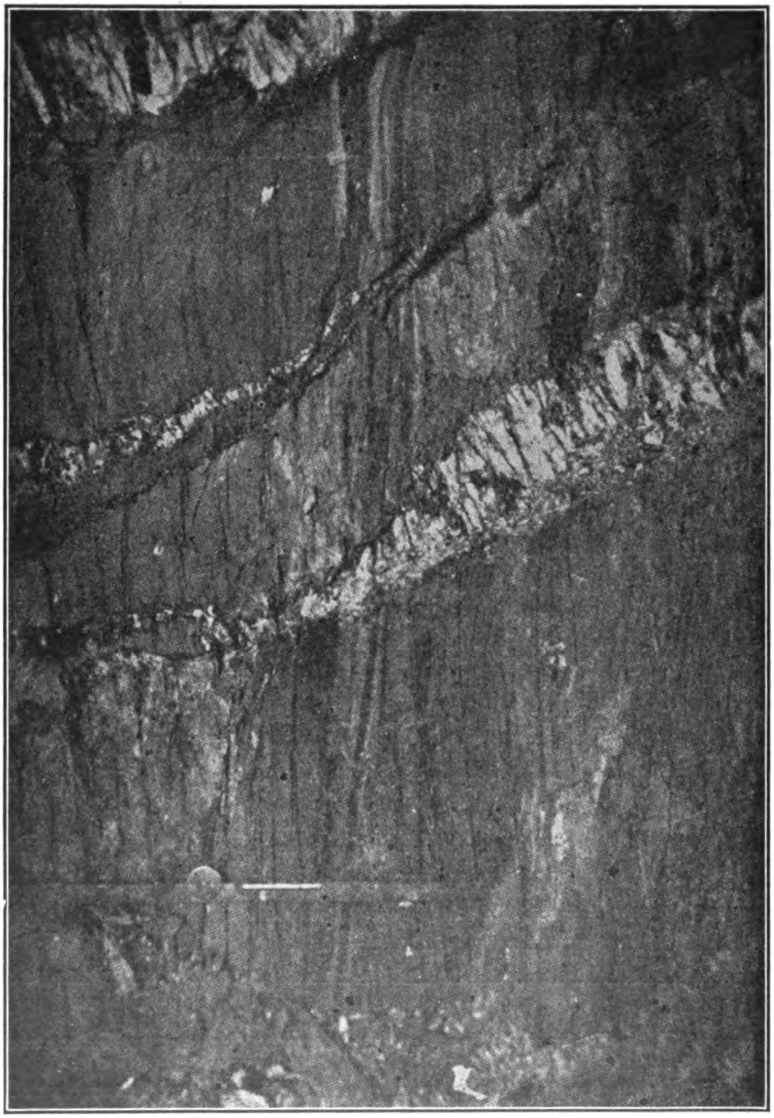


Fig. 187a.—The Indicator. 500-ft. level No. 1, Llanberris mine. (T. A. Rickard.)

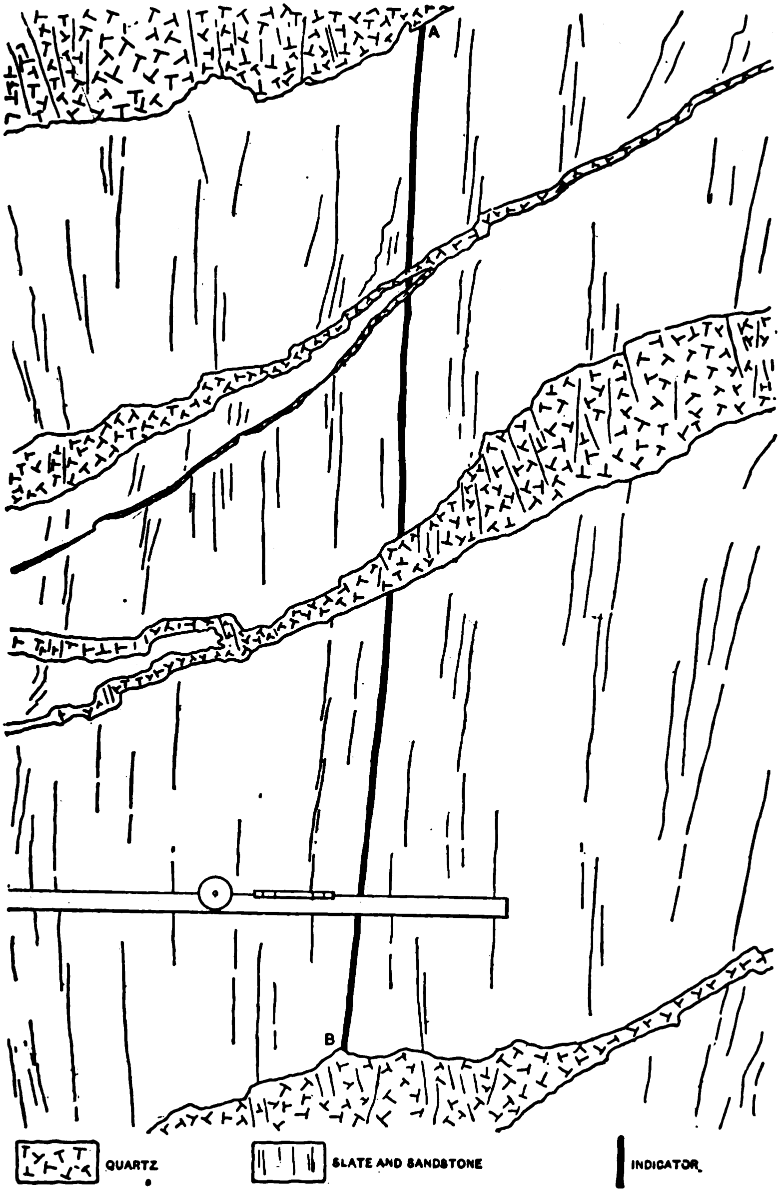


Fig. 187*b*.—The Indicator. Diagram, explaining Fig. 187*a*. (T. A. Rickard.)

argentiferous lead veins, with a quartz and barite gangue. Some of these veins, such as the Esperanza and the Gabriel, only carry ore when in the granite, becoming barren in the slate, while, on the contrary, others, such as El Castillo, are ore-bearing in the slate and barren in the granite; and yet El Castillo is only one kilometer distant from La Esperanza.

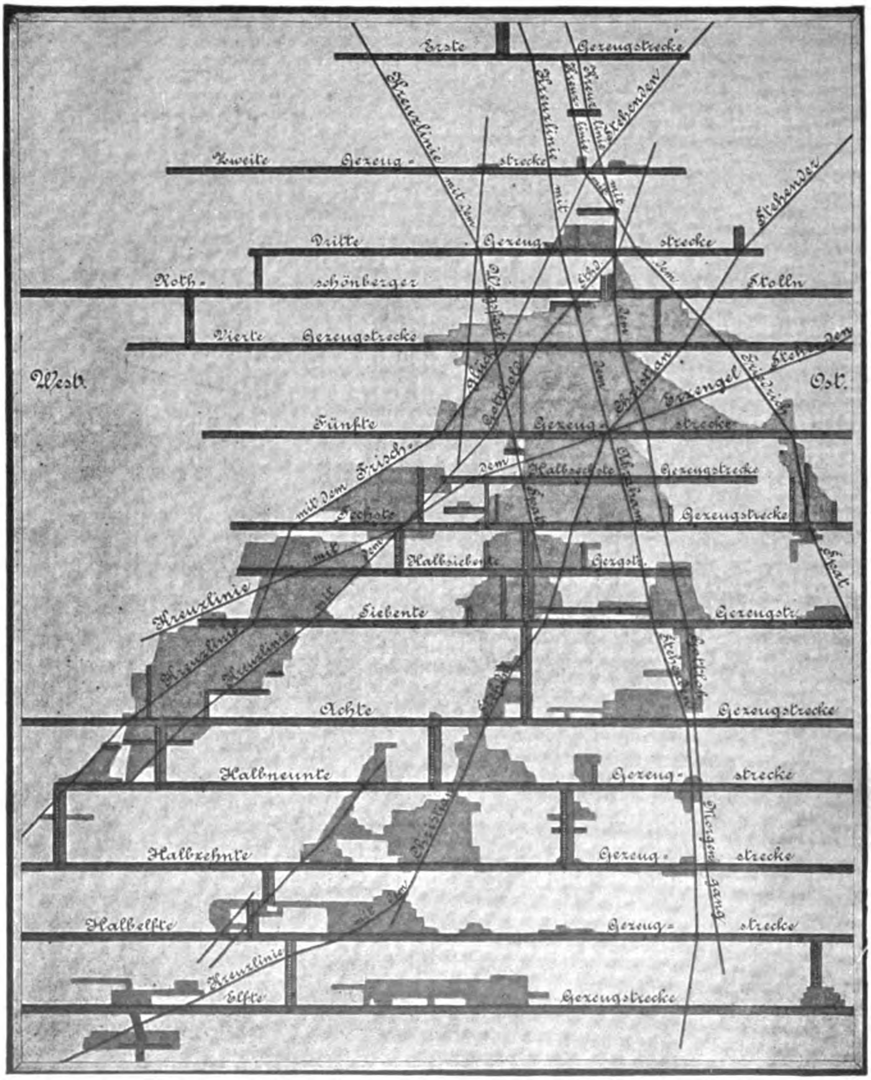


Fig. 188. – Longitudinal section along the vein of the Neu-Hoffnung Flachen at Himmelsfahrt at its crossing with several other lodes. (From plate of the Royal Mining Bureau.)

In some cases the influence of older upon younger veins is due to intersections in which the nature of the older vein filling influences the later ore deposition.

Influence of Vein Intersections on Ore Content.

The occurrence of rich ores and ore shoots at vein intersections in the lodes of the Freiberg district has long been known.

According to H. Müller, the enrichments occur both at intersections of two veins of similar mineralogic type and of those of different classes. This enrichment consists in an increased thickness of ore or of richer ore, or both these features. It is noteworthy that the rich silver ores, pyrargyrite and proustite, argentiferous tetrahedrite, argentite, polybasite and stephanite, as well as native silver, show a tendency to form at such points.

The enrichment is most marked when the veins intersect at acute angles, because the intersecting vein walls are close together and for longer distances. Hence dragging intersections, in which the angle of crossing is very small, are the richest; perhaps this is because the mass of crushed and permeable rock is much greater in acute than in obtuse or rectangular intersections.

The intersections of the lead barite Neu-Hoffnung Flachen vein with pyrite-blende-galena veins (Erzengel and Christian Stehende), of the Himmelsfahrt mine, near Freiberg, are especially famous (Fig. 188), yielding a million or more dollars. Masses of native silver weighing many hundred pounds were found there. The most noteworthy find was in 1858, when about 5,000 kilograms of silver were gotten out of the intersection between the Kalb Stehende and the August Flache. In three years $250,000 profit was made from the excavations at this intersection.

An impoverishment at vein crossings is very rare, according to H. Müller. The Abraham Morgeng vein, which is in itself an example, drags against a Spat vein for a distance of more than 105 feet (32 m.) and yet throughout that distance consists merely of gouge-filled fissure. Similar phenomena have become known from other lode areas.

Influence of Converging or Diverging Stringers on the Ore Content of Veins.

What has been said of vein crossing is also true in a lesser degree of vein stringers (splits or spurs), as shown by H. Müller[1] by numerous examples. Where two or more main stringers unite, many of the Freiberg lodes show a distinct enrichment, not only in quantity but also quality of ore, while conversely the diverging stringers grow poorer away from the main ledge and finally become completely barren.

[1] H. Müller: 'Erzgänge des Freiberger Bergrevieres,' 1901, pp. 297–304.

This phenomenon is repeated in many other regions. For example, F. Klockman says[1]: "The rule that the richest orebodies occur at the points where the lodes unite is verified throughout the vein area of the upper Harz."

The real cause of the enrichment of veins at intersections, and where stringers converge or diverge, may in part be due to a mixture of two chemically different solutions and the various reactions thence resulting. Such reactions might occur even when one lode had originally no metallic content, since in point of fact rich intersections with barren fissures are well known in certain lodes. If, on the contrary, one of the fissures already had a solid mineral filling, the causes fall within the scope of the second article after the next, since the pre-existing filling in this case figures merely as country rock.

In lodes of the same age the vein junctions present favorable conditions for ore deposition because the fissure spaces available for the deposition of ores might be wider and thus remain accessible to the circulating solutions for a longer time than elsewhere.

Influence of the Folding of a Stratified Country Rock on the Richness of Veins.

Where mineral veins cut through a folded system of strata the structural features of that system have sometimes exerted a manifest influence on the ore content. Thus, according to J. A. Church[2], at Tombstone, Arizona, the largest orebodies occur where the veins intersect the anticlines of Carboniferous limestones, quartzites and slates. Horizontal orebodies also occur in the form of epigenetic stocks along the anticlines, consisting in the main of gold-bearing silver-lead ores, the mineralization being confined to certain beds of limestone and quartzite. The fissures, however, carry ore at points where the slate of the anticlines forms the country rock.

Cause of the Influence of Country Rock on the Distribution of Ore[3].

Although from the preceding statements it appears that the distribution of ore in mineral veins is influenced by the nature of the country rock, yet

[1] F. Klockmann: 'Berg und Hüttenwesen des Oberharzes,' 1895, p. 48. Zirkler: 'Ueber die Gangverhältnisse der Grube Bergmannstrost bei Clausthal.' *Glückauf*, Essen, 1897, p. 93.

[2] 'The Tombstone, Arizona, Mining District,' *Trans.* Am. Inst. Min. Eng., May, 1902.

[3] C. Le Neve Foster: 'Ore and Stone Mining,' 1894, p. 12. W. H. Weed: 'Influence of Country Rock on Mineral Veins.' *Trans.* Am. Inst. Min. Eng., Vol. XXXII, November, 1901. 'Amer. Geol.,' 1902, Vol. XXX, p. 170.

both in individual cases and in general it is quite difficult to ascertain the true cause of this influence. It must be confessed that our knowledge of this subject has advanced but little since the time when B. von Cotta[1] wrote his 'Materialien zu Einer Theorie,' aside from the question of lateral secretion, to be treated connectedly later on.

Not only does the character of the fissuring vary in different rocks, which is a mechanical feature, but there is a variation in the amount and value of the ore, particularly the richer ore. While this latter feature is a chemical one, it is of great practical significance. The solution of these questions is, in the main, a purely chemical problem. The deposits in which the ore minerals of the vein filling have been derived from the country rock immediately adjoining the vein by leaching, a phenomena which, of course, involves a direct genetic connection between the two, will be described in a special section. But even if we admit that both the metallic and non-metallic minerals have been brought into the vein fissures from a distance and by ascending currents, there must be some chemical reaction between the vein-forming solutions and the minerals of the wall rocks and this must have some influence on the distribution of the minerals of the vein.

There is convincing proof that zones of very bituminous or carbonaceous rocks exercise a markedly favorable influence upon the contents of veins passing through them, and this is due to a reduction of the sulphates in solution by the carbonaceous material[2]. For other rocks it is not so easy to determine the exact nature of this relation. The replacement of the silicate minerals of a rock by ores as a result of a decomposition of these minerals by the vein-forming solutions was first discussed in detail by G. Bischof[3]. At Freiberg the evident relation between orebodies and the "normal Freiberg gneiss," a granular-fibrous mica schist or biotite gneiss, has been carefully investigated by several geologists. Special chemical investigations carried on by Th. Scheerer[4] led him to announce a theory for this relationship. This author started with the fact (demonstrated by H. Müller) that the biotite gneiss is a much more favorable wall rock for rich ores than the muscovite gneiss, and concluded that the biotite is the real cause of this favorable influence. He thought that the black mica, owing to its holding an excess of weak bases, especially ferrous oxide and manganese, offered far less resistance to the action of acids than the light col-

[1] B. von Cotta: 'Lehre von den Erzlagerstätten,' I, p. 148, *et seq.*

[2] W. P. Jenney. 'Chemistry of Ore Deposition,' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Bischof: v. Leonhard's *Jahrb.* f. Min., etc., 1844, pp. 257–341.

[4] Th. Scheerer: 'Die Gneuse des Sächs. Erzgebirges und verwandte Gesteinenach ihrer chemischen Constitution und geol. Bedeut.' *Z.* d. D. G. G., 1862, p. 23 *et seq.*

ored mica. Under this supposition Th. Scheerer imagines the process of lode filling to have taken place as follows:

Carbonated water containing hydrogen- or alkaline-sulphides leaches the deep zone of heated rocks and extracts SiO_2, CaO, BaO, metallic sulphides and compounds of arsenic and antimony, and carries its chemical burden into the upper parts of the fissures. There the precipitation and deposition of these substances takes place, partly through a diminution of pressure and temperature, and partly by a reaction between the solution and the biotite of the gneiss of the vein walls. The biotite is decomposed by the surplus CO_2, yielding $FeCO_3$ and $MgCO_3$, thus indirectly causing a decomposition of the earthy bicarbonates, which lose their solvent CO_2 and are deposited to form the carbon-spars so common in veins. Meantime the H_2S or the alkaline sulphides act on the newly formed iron carbonate, and pyrite is precipitated and, as the decomposition of the mica progresses, the other metallic compounds of the solution are finally precipitated. The foliated structure of the biotite, with its interlocking scales, is a condition particularly favorable to the lateral progression of this decomposition. The particles of metallic sulphides which occur disseminated through the decomposed gneiss on both sides of the veins also prove the precipitating influence of the biotite.

This theory has the disadvantage that it is not applicable to mineral veins of entirely similar composition in districts in which neither the brown mica nor a chemically similar mineral is present in the country rock. We reproduce Scheerer's explanation because this form of the hydro-thermal theory, to be discussed a little further on, has lately been resuscitated and expressed in closely similar terms.

The enriching influence of vein intersections has been often explained as due to electrolytic processes, and an analogous explanation has been applied to the influence of the fahlbands in Kongsberg.

Skey has shown that, for example, an element, consisting of a piece of kaolinite and a bit of pyrite immersed in sea water, is able to precipitate the metal from a solution of copper sulphate, and Chr. A. Münster[1] proved that samples of pyritic schist (fahlband) caused a precipitation of the silver from a solution of Ag_2CO_3. It is supposed that many instances where native silver occurs at vein crossings are susceptible of similar explanation.

That electric currents do sometimes exist in mineral veins was proved many years ago by Fox, Henwood, von Strombeck and Reich[2], and was

[1] Cited by P. Krusch: 'Kongsberger Erzrevier.' *Zeit. f. Prak. Geol.*, 1896, p. 101.

[2] F. Reich: 'Leitfaden zu den Vorlesungen über Physik.' Part II, 1853, p. 62.

confirmed anew by Barus[1] and Erhard[2]. Reich in Freiberg reached the following conclusions:

(1) Two particles of ore in a mine, separated from each other either by barren rock, or a cross vein, or an opening (natural or artificial), generate an electric current when connected by a metallic wire.

(2) Two particles of ore in constant contact with each other give no current when connected by a wire.

(3) Two samples of rock free from ore minerals give as a rule a current when there is ore near by.

(4) The electro-motive force producing the currents is always much smaller than one daniell (somewhat less than one volt).

Th. Erhard has described very convenient methods for investigations of this sort, but states that they are not of any practical use in hunting for new orebodies.

That the influence of the country rock on the mineralization of a vein may, however, be due to a combination of other factors, such as difference in conductivity of heat, porosity, smoothness or roughness of the rock surfaces, etc., has been set forth by B. von Cotta[3]. Direct proof in individual cases is still lacking.

The Action of Vein-Forming Solutions Upon the Wall Rock.

The influence of the vein-forming solution upon the walls of the fissure is quite apparent. In fact, the rock directly adjoining mineral veins rarely shows its original habit, having nearly always undergone some chemical or mineralogical change. Inasmuch as we shall later on, in discussing the various theories of vein genesis, give our support to the thermal theory, at least for the great majority of the mineral veins, we can, admitting the correctness of this theory, conceive these changes as rock alterations due mainly to rising thermal waters, and we shall accordingly speak of a hydro-thermal alteration[4] of the country rock, excluding in the discussion so far as possible the alterations in the upper parts of veins that result from later operations, or post-thermal influences.

In most cases the various chemical changes of the country rock have been preceded, and the rock prepared for ready alteration, by strong

[1] Barus: 'On the Electrical Activity of Ore-Bodies,' in G. F. Becker's 'Comstock Lode.' 2d *Ann. Rep.* U. S. Geol. Surv., 1882, pp. 320–324.

[2] Th. Erhard: 'Ueber die elektrischen Ströme auf Erzgängen.' *Jahrb.* f. d. Berg- u. Hüttenw. im K. Sachsen, 1885. pp. 1–15.

[3] B. von Cotta: 'Lehr von den Erzlagerstätten,' Vol. I, pp. 149-151.

[4] H. Rosenbusch: 'Studien im Gneissgebirge des Schwarzwaldes.' Heidelberg, 1899, p. 16.

mechanical forces, producing fissuring, distortion and crushing during the formation of the fissures.

This alteration is usually recognizable by a more or less pronounced bleaching or discoloration of the rock and a loss of hardness. This is the condition designated by the miner as "faul" (rot). In fact, the word gneiss (gneuss) is very probably due to this peculiarity, which must have been the first thing recognized by the miner, throughout the lodes of the Erzgebirge, when the first prospecting work was being done, the region being at that time half Slavic.

In Wendish *gnisch* means to rot and *gnoj* means manure, which words, according to Kalkowsky[1], are from the same root as gneuss. It had probably been long suspected that this bleaching of the rock along the vein fissures was due to the removal of the iron compounds and other chemical changes. This bleaching is especially striking when the country rock is originally dark or of brilliant color, as for example, the hornblende schist of Kongsberg, or at Freiberg, the quartz porphyry. The only accurate investigation of the subject is that made by Th. Scheerer[2], in Freiberg. From a comparison of a number of accurate analyses of both the fresh biotite gneiss and the decomposed country rock of the veins, he inferred that during the alteration the gneiss had first lost a considerable amount of silicic and titanic acid, and fully 15.2% out of the 18.8% of fixed bases contained in the normal gneiss as complex aluminous silicates. Among other things 96.5% of the total quantity of iron oxide had been withdrawn from the rock. The water content had risen from 1 to 2.5%. Furthermore, Scheerer's analyses proved an immigration of metallic sulphides into the decomposed gneiss, a fact manifest to the eye.

Similar investigations were soon after made by R. Pearce[3], later by von Groddeck[4] and recently by Stelzner, Lindgren[5] and others. The last-named author has shown by his very careful work the importance of metasomatic processes in vein formation, and has classified veins according to the nature of the metasomatism. Sometimes mineral veins show evidences of two periods of dissimilar character. The rather complicated and in

[1] E. Kalkowsky: 'Die Gneissformation des Eulengebirges.' 1878, p. 14.

[2] Th Scheerer: 'Die Gneuse des sächs. Erzgeb.,' etc. *Z.* d. D. G. G., 1862, Vol. XIV, p. 89 *et seq.*

[3] R. Pearce: 'The Influence of Lodes on Rocks,' *Rep.* Miners Assoc. Cornwall, Truro, 1864, p. 18.

[4] A. v. Groddeck: 'Zur Kenntniss einiger Sericitgesteine, welche neben und in Erzlagerstätten auftreten.' *N. Jahrb.* f. Min., 1882, vol. II, pp. 72–138. Also 'Studien über Thonschiefer, Gangthonschiefer und Sericitschiefer.' *Jahrb.* d. Kgl. preuss. geol. Landesanst., 1885, pp. 1–52.

[5] W. Lindgren: 'Metasomatic Processes in Fissure-Veins.' *Trans.* Am. Inst. Min. Eng., February, 1900.

many ways interrelated phenomena are for convenience separated into classes. The first and the commonest is sericitization.

SERICITIZATION.

A. von Groddeck, using a great number of bulk analyses, proved that clay shales, graywacke slate and similar rocks occurring alongside of or near mineral veins (fissure or bedded) are often changed into sericite-rocks, the original chloritic constituents being leached out and newer carbonates and quartz being formed. His work treated mainly of the rocks of the vein districts, Holzappel, Wellmich and Werlaw, where the altered country rock had long attracted attention and was known as 'Weisses Gebirge' (white rock). He also studied the so-called Lagerschiefer of Mitterberg, the white slates about the pyrite deposit of Agordo and the clay slates of the veins of the upper Harz.

In the slate fragments of the vein filling, which consist of completely crushed and ground Culm slates, Gröddeck states that the chemical change is unmistakably due to the solutions forming the veins. In the black slates this chemical action shows in a progressive leaching out of the original ferric oxide and magnesia content, a process which has reached its completion in the variegated varieties. From numerous careful analyses he found the average composition to be as follows:

	Culm clay shales.	*Slate of Vein Filling.* *Black.*	*Variegated.*
FeO	4.87 per cent.	1.06 per cent.	0.00 per cent.
MgO	1.80 "	1.11 "	0.00 "

From the chemical analyses and a microscopic investigation it was shown that the normal slates, of the Culm and Devonian formations of the upper Harz region, consist of quartz and sericite and a chloritic mineral, with small amounts of rutile, carbonaceous material and various carbonates. The analyses show that while in the black slate of the vein filling the percentage of quartz is almost unchanged, the amount of sericite, which is about 39% in the normal slate, has increased to 47%. In the variegated slates of the vein filling the silica has increased from 35 to 63%, with a corresponding decrease of the sericite to about 35%. These last named rocks consist of a mixture of quartz and sericite, with a little rutile and considerable specular iron. The chlorite has been completely removed.

At Freiberg, the investigations begun by Scheerer were continued by A. W. Stelzner with improved methods and much greater accuracy. This work demonstrated that alongside of the veins the gneiss is altered to a clayey decomposition product in which the zircon and apatite remain quite fresh, while the chief minerals of the gneiss, viz., quartz, feldspar and mica, have been wholly or almost completely altered to potassium mica (sericite). This mineral occurs in minute scales of hexagonal or rounded outline and in small round aggregates, which form the bulk of the decomposed gneisses. This material, separated by Stelzner from the altered country rock adjoining the Dietrich Stehenden vein, Himmelfahrt mine, Freiberg, has been analyzed by H. Schulze; it has the following composition:

SiO_2	47.88
TiO_2	Trace
SnO_2	0.02
Al_2O_3	35.16
Fe_2O_3	1.92
CaO	0.48
MgO	1.11
K_2O	10.08
Na_2O	0.41
H_2O	4.02
F	?
Total	101.08

Moreover, this clayey decomposition product of the gneiss contains newly formed rutile needles and small plate-like crystals of octahedrite. The last named mineral, however, is also formed by the normal decomposition of the gneiss at the earth's surface. Finally, the rutile is accompanied by fine brown needles, determined as cassiterite, since 11.44% of SnO_2 was found in the heaviest portion of the clayey ingredients. While the material for the titaniferous minerals is found in the biotite of the gneiss, the tin must come from the vein fissure, and in fact the vein is known to contain cassiterite-bearing zinc-blende.

The crystals of arsenopyritē, so often found scattered through the decomposed gneiss of Freiberg, certainly result from the immigration of material from the vein. In the Morgenstern mine arsenopyrite is so abundant in the vein wallrock that the rock was mined for that mineral. At this same locality the decomposed country rock also contains widely distributed secondary impregnations of pyrite, galena, sphalerite and native silver[1].

A remarkable impregnation of decomposed gneiss with cuprite, braunite, blende and galena occurs in the Weisser Lowe Spat, southeast of Freiberg, the two first named minerals being entirely absent in the stringer veins themselves.[2]

[1] B. v. Cotta: 'Erzlagerstätten.' Vol. I, 1859, p. 209 *et seq.*

[2] W. Vogelgesang: 'Erzgänge südöstl. von Freiberg.' 1854. Cotta's Gangstudien, II, p. 82. Compare with F. Sandberger: 'Untersuchungen über Erzgänge,' II, p. 343.

Sericitization, as this alteration is termed, is a common feature of American mineral veins. It is a characteristic feature of the Butte, Montana, copper veins and, according to Lindgren, is typical of many gold veins in granite, especially in Idaho. It takes the place of the kaolinization typical of normal weathering. In the gold-quartz veins of California[1] sericitization is accompanied by a segregation of calcite, which, however, is a subordinate mineral in the lodes themselves. In this alteration the normal ferromagnesian silicates and feldspars of the granite are first attacked and altered to aggregates of sericite and calcite, the sericite sometimes passing through a chloritic transition stage. Next the quartz, too, is replaced. Ilmenite is changed to rutile, and a migration of new material appears in the form of sulphides, especially pyrite, as well as arsenopyrite, sometimes carrying inclusions of sericite scales.

The following analyses given by Lindgren illustrate the character of the alteration:

I is a fresh granite (by G. Steiger).

II is a sericitized granite, both from Idaho, Silver Wreath tunnel, Boise district (by G. Steiger).

III is a fresh diabase from Grass Valley, California (by H. N. Stokes).

IV is a diabase from the vein wall; North Star mine, same locality (by W. F. Hillebrand).

Analyses of Fresh and Altered Rock.	I	II	III	IV
SiO_2	65.23	66.66	51.01	45.74
TiO_2	0.66	0.49	0.98	0.36
Al_2O_3	16.94	14.26	11.89	5.29
Fe_2O_3	1.60	0.67	1.57	0.13
FeO	1.91	2.41	6.08	9.06
FeS_2	.....	......	1.73	0.49
MnO	Trace.	Trace.	Trace.	0.26
CaO	3.85	3.37	10.36	23.85
BaO	0.19	......	.....	......
MgO	1.31	0.95	8.87	0.94
K_2O	3.02	4.09	0.15	1.29
Na_2O	3.57	......	4.17	0.11
H_2O under 100° C.	0.18	0.36	0.24	0.22
H_2O over 100° C.	0.88	2.16	2.09	1.07
P_2O_5	0.19	0.17	0.17	0.07
SO_3	.....	......	.....	......
S	.....	0.95	.....	......
CO_2	0.25	3.67	.....	18.91
	99.78	100.31	99.31	100.79

In the altered granite, small newly formed crystals of pyrite and arsenopyrite occur. The feldspar has disappeared, or at most only its outlines

[1] W. Lindgren: 'The Mining Districts of Idaho Basin,' etc. Extr. 18th *Ann. Rep.* U. S. Geol. Surv., 1898. Also 14th *Ann. Rep.*, part II, pp. 243–284, and 17th *Ann. Rep.*, part II, p. 144. Also *Bull.* Geol. Soc. Am., Vol. VI, p. 221. Also 'Metasomatic Processes in Fissure-Veins.' *Trans.* Am. Inst. Min. Eng., February. 1900, p. 80.

are well recognizable. The biotite has been replaced by sericite; titanite has become turbid; menaccanite has given rise to segregations of rutile; apatite has remained unchanged. This altered rock contains 1.55 grams of gold and 15.55 grams of silver per ton. In this process of sericitization even the quartz is attacked, particularly when calcite has been formed simultaneously with the sericite.

Lastly mention may be made of the replacement of the quartzite country rock of the silver-lead veins of the Coeur d'Alene Mountains in Idaho, into an aggregate of siderite with galena, pyrite and zinc-blende[1].

KAOLINIZATION.

In certain cases the country rock is kaolinized, though it is now known that most of the cases so described are really examples of sericitization. According to J. Church[2], kaolinization occurs in the andesitic rocks of the Comstock Lode, being formerly regarded by him as the cause of the great heat of the water rising in that lode, the cause being thus confounded with the effect. Kaolinic formations also play a great part in the ore deposit of Broken Hill.

The gold veins of Nagyág are accompanied by masses of altered rocks, which have been carefully investigated. The clayey material resulting from a decomposition of the hornblendic dacites (andesite) represents an incipient kaolinization, first described by B. von Inkey[3]. A large amount of such clay was separated by F. Kolbeck[4] into its various components by means of elutriation, treatment in iodide solutions, etc. The most abundant ingredient was a mineral typical of micaceous schists. This light, greenish-gray, fibrous, scaly-textured mineral was analyzed. The composition, after F. Kolbeck, is given under A. Minute crystalline groups of arsenious, auriferous and argentiferous iron pyrite crystals, were also noted together with rounded aggregates of octahedrite, murky plates of barite, short columns of apatite and crystals of zircon of ideal sharpness. The last two minerals are primary, unaltered minerals of the dacite. The chemical composition of this rock, after Doelter[5], is given under B.

Analyses of Kaolin and Altered Rock.	A	B
SiO_2	48.67	58.01
Al_2O_3	39.30	18.19
Fe_2O_3	0.30	3.40

[1] Lindgren: Metasomatic Processes, etc., *op cit.*, p. 103.
[2] J. A. Church: 'The Comstock Lode,' *Trans.* Am. Inst. Min. Eng., 1879.
[3] B. v. Inkey: 'Nagyág und seine Erzlagerstätten.' Budapest, 1885.
[4] F. Kolbeck: 'Untersuchungen über die Zersetzung des Quarztrachytes neben den Golderzgängen von Nagyág.' *Oesterr. Z.* f. B. u. H., 1888, No. 3, p. 25.
[5] In Tschermak's 'Mitth.' 1873, part II, p. 95.

Analyses of Kaolin and Altered Rock.	A	B
FeO	....	2.89
MnO	0.25	Trace.
CaO	0.38	7.55
MgO	1.42	3.01
K_2O	3.73	1.39
Na_2O	0.13	3.92
H_2O	5.83	1.60 loss by ignition
CO_2	0.23	.....
FeS_2	0.43	.....
	100.67	99.96

PROPYLITIZATION[1].

Various authors[2] have shown that the propylitic alteration of andesitic and trachytic rocks is also due to hydrothermal metamorphism accompanying the formation of mineral veins. The mode of occurrence of these rocks is best exhibited in the section Fig. 173. We cannot characterize the nature of the propylites more fitly and briefly than with the words of H. Rosenbusch:

"The names quartz-propylite and propylite (F. von Richthoven) are used to designate a greenstone-like facies of dacitic and andesitic rocks found almost always at points where these rocks have acted as bringers of ore" (that is to say, are traversed by mineral veins). "The name propylite arose from the supposition that these rocks are everywhere the oldest Tertiary eruptive rocks, as is the case in some places, and after a long period of volcanic rest reinaugurated, as it were, the eruptive processes during the Mesozoic epochs" (*pro pyle*=at the gate). The name greenstone-trachyte is an older synonym. Propylitic rocks occur near large fissure veins and vein systems in Hungary and Transylvania; at the Comstock Lode, Nevada; at Pachuca and elsewhere in Mexico, and in the Andes of South America, etc. The characteristic feature of the propylitic facies consists in the loss of the glassy habit of the feldspars; in the chloritic alteration of the hornblende, biotite and pyroxenes (often with an intermediate stage of a uralite) with an accompanying development of epidote. There is a simultaneous alteration of the normal andesitic groundmass into holycrystalline granular aggregates of feldspar, quartz, chlorite, epidote and calcite, and in a considerable development of pyrite. The impregnation with pyrite points to hydrothermal processes as the common cause of both the ore content and of the alteration of the rocks, which as

[1] G. F. Becker demonstrated the secondary nature of propylite in his work on the Comstock lode. · See *Monograph* No. III, U. S. Geol. Survey. (W. H. W.)

[2] M. E. Wadsworth: *Bull.* Mus. Comp. Zool., 1879, Vol. V, pp. 281-286. B. v. Inkey: 'Nagyág und seine Erzlagerstätten,' Budapest, 1885. H. Rosenbusch: 'Elemente der Gesteinslehre,' 1898, pp. 302-303. Also 'Comstock Lode,' p. 329, l. c. H. Böckh: 'Vorl. Bericht über das Altersverh. d. Eruptivg. v. Selmeczbánya,' 1901, Földtani Közlöny, Vol. XXXI.

shown by Lindgren is very different from normal weathering. Analyses 1 and 2 below give the composition of such rocks. The propylitic alteration also occurs with certain modifications in trachytes and liparites, and is indeed also found in the more basic rocks of the basalt, melaphyre and diabase families.

Analyses of Comstock Rocks.	1	2
SiO_2	66,34	64,62
Al_2O_3	14,80	11,70
Fe_2O_3	4,07	..
FeO	..	8,39
MgO	0,92	1,18
CaO	2,99	8,96
Na_2O	5,16	3,13
K_2O	3,19	1,95
H_2O	3,34	1,02
	100.81	100.95

1. Quartz propylite, Golconda, Washoe.
2. Quartz-free propylite, Sheep Corral cañon, Virginia range, Washoe.

SILICIFICATION.

A silicification of the country rock, sometimes preceded by dolomitization, is frequent both in and alongside of veins cutting limestones. As described by Lindgren[1], the limestone is in such cases usually transformed into an exceedingly fine crystalline aggregate of interlocking quartz grains (jasperoid). Sometimes, despite a complete replacement, the approximate outlines of foraminifera, shells and other fossils may be recognized in it. Similar aggregates of vein quartz are distinguished by a much coarser grain. Minute quartz dihexahedrons are also known in limestones of mining regions, for example, from Bleiberg, in Carinthia. Feldspars and even hornblende and other bisilicates may also be replaced by quartz. At Altenberg we sometimes find a silicification of the rocks near tin veins. This phenomenon is of very common occurrence in the country rock of the quicksilver veins of California. It also occurs in some lodes of Schemnitz[2]. Sometimes the dolomitization and silicification of limestones is also accompanied by an introduction of iron as siderite or as pyrite.

ALTERATION OF LIMESTONE INTO ORE-BEARING PYROXENE-EPIDOTE ROCKS.

According to G. vom Rath[3] and B. Lotti[4] the Eocene clay shale and intercalated limestone beds, in which the quartzose copper veins of Capanne

[1] W. Lindgren: 'Metasomatic Processes in Fissure Veins.' *Trans.* Am. Inst. Min. Eng., Vol. XXX, p. 578.

[2] H. Böckh: l. c., p. 398.

[3] G. vom Rath: 'Aus der Umgeb. v. Massa Marittima,' *Z.* d. D. G. G., 1873.

[4] B. Lotti: 'Descr. geol.-mineraria dei Ditnorni di Massa Marittima,' Rome, 1893, pp. 73-75.

Vecchie and Serrabottini occur, near Massa Marittima, has undergone a very peculiar metamorphism. While the clay slate remains unaltered, or is slightly silicified and coated along transverse fissures with crusts of epidote and quartz, the limestone beds have either been altered into an aggregate of pyroxene and epidote, carrying pyrite, chalcopyrite, blende and galenite, or have been replaced, wholly or in part, by a mixture of silica and pyrite.

The phenomenon strongly suggests the action of contact metamorphic processes accompanying plutonic masses.

Alteration of the Country Rock into Greisen or Zwitter.

In tin veins the country rock is altered for a distance of several centimeters from the vein walls, sometimes even more, into 'tin stuff' (zwitter), or, as it is called in granitic country rock, greisen. This fact has long been known, having been described and figured by J. F. W. Charpentier, from the Erzgebirge, and subsequently has been carefully studied by the searching methods of modern petrography. Much has already been said on this point in treating of tin veins, page 202.

The alteration consists in the complete replacement of the feldspar and brown mica by quartz, together with lepidolite, topaz, tourmaline, fluorite, kaolinite, cassiterite, arsenopyrite, wolframite and other minerals characteristic of the tin deposits. When this rock contains much cassiterite and topaz, it becomes pay ore and the alteration bands are workable pay-streaks. In this way the beautiful pseudomorphs of cassiterite and quartz are formed as replacements of the large orthoclase crystals, which occur as phenocrysts in granite from St. Agnes, in Cornwall. The chemical composition of the greisen or zwitter varies with the mineralogic constitution of the original rock.

In an alteration of this nature the Altenberg granite has lost about 3% silica and 2% potash and has taken up 4% ferrous oxide and ½% oxide of tin.

The following table shows the chemical composition of the normal and the altered rock (after K. Dalmer[1]):

	1	2	3
SiO_2	74.68	70.41	79.73
TiO_2	0.71	0.49	..
SnO_2	0.09	0.49	1.43
Al_2O_3	12.73	14.86	14.31
Fe_2O_3	..	1.42	..
FeO	3.00	5.09	..
MnO	..	0.29	..

[1] K. Dalmer: 'Erläuterungen zu Section Altenberg-Zinnwald,' Leipzig, 1890, p. 56.

	1	2	3
CaO	0.09	0.21	..
MgO	0.35	0.09	..
K_2O	4.64	3.01	..
Na_2O } Li_2O }	1.54	0.98	..
Fl	Not det.	3.10	4.53
	99.50	100.44	100.00

1. A normal granite from Altenberg (analysis by Rube).
2. Greisen made from it; poor in quartz and rich in lepidolite (Dalmer).
3. Another specimen of the same kind especially rich in quartz and topaz (Dalmer).

When a porphyry or schist constitutes the country rock the 'zwitter' formed from them varies accordingly.

Further data on the cassiterite content, etc., of greisen, are found on page 215.

At Thelemarken, Norway, the granite adjacent to the copper veins and stringers is altered to greisen[1], whose mica is free from lithia.

Greisen may also occur about silver-lead veins, as shown by the description by Haworth of the silver mines east of Ironton, Missouri[2]. Veins of quartz, argentiferous galenite, iron pyrite, and chalcopyrite supposedly of pre-Cambrian age, traverse a granite which along the vein walls has been transformed into a true greisen. The simultaneous occurrence of zinnwaldite, topaz, fluorite, wolframite, muscovite and sericite, proves these lodes to closely resemble true tin veins.

Tourmalinization and Topazization.

A closely allied phenomenon to that just described is the impregnation of the country rock of veins with tourmaline.

This feature has long been known in the small vein fissures formerly worked for tin ore, which contain quartz, tourmaline and cassiterite, and lie in andalusite-mica-rock of the Auersberg region, near Eibenstock, in the Saxon Erzgebirge. The unaltered rock is itself the result of the contact metamorphism of a phyllite by a tourmaline granite. The impregnation of the vein wallrock with tourmaline, together with quartz, cassiterite, chalcopyrite, and in rarer cases with traces of gold, extends for a distance of about 0.5 meters from the vein (Schröder[3]). Fig. 189 gives a section of such a zone of impregnation.

[1] Lindgren objects to this use of the term greisen. 'Metasomatic Processes in Fissure Veins,' 'Genesis of Ore Deposits,' Am. Inst. Min. Eng., p. 563.

[2] Missouri Geol. Survey, 1895, Vol. VIII, p. 83.

[3] M. Schröder: 'Erläuterungen zu Section Eibenstock,' Leipzig, 1884, p. 38.

On a large scale tourmalinization and topazization of the country rock of tin veins has taken place on Mount Bischoff, in Tasmania, as will be related in detail under the heading of 'Tin Placers.' The quartz crystals of the slate of that locality show various gradations to a complete replacement and the formation of tourmaline-fels. The alteration is especially marked in the case of quartz porphyries whose orthoclase phenocrysts are replaced by cassiterite, pyrite, magnetite, arsenopyrite and fluorite.

This is the most appropriate class in which to place the topaz rocks (Topasbrockenfelse) from the old tin deposits of Schneckenstein, on the western border of the same Eibenstock granite mass studied by Schröder[1]. The deposits hold fragments of tourmalinized schist cemented by topaz, while near by the quartz porphyry dikes of the Saubach Valley show intense topazization.

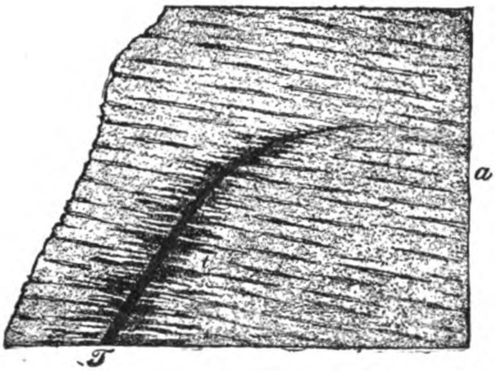


Fig. 189.—Impregnation of the country rock with tourmaline. (M. Schröder.) a, andalusite mica rock: T, tourmaline-quartz vein: t, tourmaline schist.

A tourmalinization of the country rock has also been observed in the gold-bearing copper veins of Chile (see p. 220).

As an appendix mention may also be made of the fluoritization of the crystalline limestone of Berggiesshübel in the vicinity of stringers of the tin veins. The quartz-fluorite mixture of Cripple Creek, too, is regarded by W. Lindgren as formed by metasomatic replacement of feldspar and other minerals.

Metasomatic Replacement of Country Rock by Ore.

This process, which has been repeatedly referred to already, is of widespread occurrence. It has been very carefully studied by W. Lindgren. This author has described replacements of country rock by pyrite, mar-

[1] M. Schröder: 'Erläuterungen zu Section Falkenstein,' Leipzig, 1885 p. 40.

casite, chalcopyrite, arsenopyrite, magnetite, kaolinite, zinc-blende, native gold, silver and copper. The occurrence of disseminated crystals and grains of these sulphides in country rock has been known for a long time, as already mentioned.

The proof that these scattered sulphide minerals are due to replacement has been demonstrated by Lindgren by the study of thin sections under the microscope. As an example we may mention the micro-structure of galena ores of Elkhorn, Mont. Fig. 190 shows in thin section the replacement of a crystalline dolomitic limestone by this ore. This mineral is apt to replace calcite and dolomite, also quartz and silicates, as will be shown in the de-

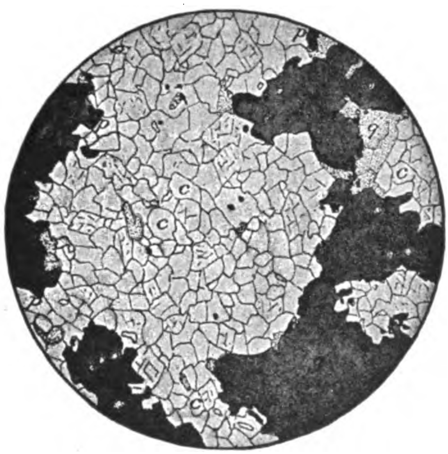


Fig. 190.—Limestone (c) replaced by galena (g), prite (p) and secondary quartz (q). Elkhorn Mine, Montana. (Enlarged 12 times.)

scription of epigenetic ore stocks. The long known alteration of the Zechstein limestone close to the mineral veins of Kamsdorf belong to this category.

ALTERATION OF THE HANGING-WALL ROCK.

T. A. Rickard[1] was the first, so far as we know, to point out that the two walls of a lode often show a great difference in the degree of decomposition. In the hanging-wall the country rock is usually changed into sericite or other alteration products, to a much greater distance than in the foot-wall. The explanation of this observation, which needs confirmation by extended observations in other districts, may be the following: in the masses of gravel

[1] T. A. Rickard: 'Vein-Walls,' *Trans.* Amer. Inst. Min. Eng., Vol. XXVI, 1897, p. 193.

and gouge produced by friction of the vein walls, the clay settles out through gravity on the foot-wall, even when the fissures were entirely filled with ore. This foot-wall gouge forms an impervious or nearly impervious lining, preventing the thermal waters from penetrating further into the foot-wall country rock and there causing rock decomposition.

This theory agrees well with what F. A. Moesta[1] says of the so-called *mantos,* that is to say, zones of impregnation and alteration in the Jurassic limestone or country rock of the famous silver veins of Chañarcillo (see p. 279): "It is a remarkable fact that the *mantos* are developed by preference in the hanging-wall, while the continuous and perfect foot-wall is formed of unaltered rock. On the hanging-wall side of the vein the country rock is netted with numerous ore-bearing fissures and lode stringers, and is so richly impregnated with ore that its silver content rises to 1% and above, so that it is often profitably worked for a distance of 12 meters from the lode." At greater depths, indeed, the *mantos* are mostly developed on both sides of the lode, but grow generally rarer and poorer. Within this impregnated country rock (*mantos*) the lodes of Chañarcillo contain the richest orebodies. Hence Moesta believes that the original character of the country rock has had an influence in their development and that they represent zones of enrichment whose origin he associates with the intrusion of the greenstones. The rock alteration in these *mantos* consists, among other things, in a strong silicification. The following analyses made by Moesta show the chemical difference between such a *manto* and the undecomposed rock belonging to the same stratum in the foot-wall of the lode:

	Manto.	Unaltered Rock.
SiO_2	47.97	22.82
Al_2O_3	6.22	
Fe_2O_3	3.90	3.53
MgO	16.71	11.46
CaO	9.65	29.73
CO_2	11.64	31.09
K_2O+Na_2O	1.27	1.69
AgCl	1.55	..
C	..	0.93
	98.91	101.25

Geologic Age of Mineral Veins.

The origin of a vein is generally supposed to be the result of two acts which follow each other very closely: 1, the opening of the fissure; 2, the filling thereof.

[1] F. A. Moesta: 'Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen des Silbers in der Natur.,' Marburg, 1870, p. 26.

From examples already given it is inferred that fissures have been formed in all periods of the earth's history and are still forming, and hence vein fillings exhibit great variety in age. Another feature of great importance is the repeated opening of many vein fissures and the resulting formation of vein fillings of successive ages in the same vein. Such action continued for a long period may result in changes in the nature of the solutions introduced, and thus the character of the successive fillings may differ. A vein may even contain two or three bands which cannot be classified in the same group or character of vein formation. For example, some lodes of the Himmelsfürst mine near Brand consist of a band of the carbonspathic, and another of the pyritous-galena-blende veins (formation).

The age of a vein[1] can be determined within certain limits when we know the age of the rock cut out by it, and the vein is in turn cut by another rock whose age is known. Of course, this differs from a cutting off or termination of the vein as a result of a different texture or condition of coherence of the other rock (see p. 123). On the contrary, it must be known from observation that the vein had been formed before the deposition of the second rock; a fact known, for example, if fragments of the vein are found in the rock. Other criteria for the determination of age consist in the presence of other fissures of known age; fault fissures; eruptive dikes and mineral veins in which natural or artificial exposures show whether they cut off the vein in question or not. In any case one can only determine the relative age. All we can find out is whether a vein is actually younger or older than another geologic formation. The country rock cut by the vein only gives the older age limit. The vein may be very much younger than the country rock. This is especially striking in the lead or zinc deposits found (not in genuine veins) in the Silurian limestones of Missouri. In these deposits a part of the galenite and zinc-blende is of Pleistocene age, for it contains bones of *elephas* coated with galenite. The same is true of the Tertiary and Pleistocene limonites found in cavities in Jurassic limestones.

The determination of the relative age of veins may be illustrated by a few examples:

At Freiberg the ores of the silver quartz veins are traversed by quartz-porphyry dikes, whose Permian age has been demonstrated; hence they are older than the Permian. Conversely, the pyritous-blendic lead veins traverse the Permian quartz-porphyries, and hence are younger than these.

The ore lodes of Joachimsthal traverse the Permian quartz-porphyry

[1] H. Höfer: 'Zur Bestimmung des Alters der Gänge,' *Oesterr. Z. f. B. u. H.*, Vol. XLVII, 1899.

dikes, but are in the main cut by the Upper Oligocene basalts, only a few insignificant younger ore stringers being found in the basalt. Moreover, as the fissure formation of that locality very probably coincides with the main uplift of the Erzgebirge, which took place in Oligocene time, the origin of the mineral veins may be very properly referred to the Oligocene period. The same relation exists between the cobalt-silver veins of Annaberg and the basalts of the Erzgebirge. Some gold quartz veins of Australia traverse sedimentary and eruptive rocks of Silurian and Devonian age, but are themselves covered by Carboniferous rocks. The pre-Carboniferous age of those veins is also indicated by the occurrence of gold in the lowest Carboniferous conglomerates.

Sometimes it even seems possible to determine the relative age of the various divisions of the lode filling. Thus, according to F. Klockmann[1], the quartz and calcite in the mineral veins of the Upper Harz are probably of Permian age. On the contrary, the barite was probably introduced much later, during or after the Zechstein period, for at Rösteberg near Grund, barite occurs in the Zechstein dolomite. The siderite stringers and the strontianite are probably still more recent. On the other hand, the ore minerals do not seem to have been restricted to the oldest period of mineralization, for galenite also occurs in fissures and cavities in the Zechstein beds of Grund and Lauterberg. Moreover, in the upper Harz, certain veins have been clearly shown by von Koenen[2] to be of Miocene to Pliocene age.

It was formerly believed that certain types of veins were associated with definite geologic periods. Recent observations, however, show the danger of such a generalization. What is true of a limited area may not prevail over the entire surface of the globe. While, for example, at Freiberg, the rich (*edle*) quartz veins were found to be older than the Permian, in the closely similar occurrences in Mexico the post-Jurassic age has been proved beyond doubt (p. 266). Thus, in former times, when all granites were regarded as Paleozoic or older, that age was also assigned to the tin lodes associated with the granites. At present, however, occurrences of both are known which are much younger. The lodes of Altenberg and Zinnwald, for example, are, according to K. Dalmer[3], of post-Carboniferous age, and in the province of Pisa, in upper Italy, tin veins cut Liassic strata.

Gold vein deposition is, according to Lindgren, associated with certain

[1] F. Klockmann: 'Berg- und Hüttenwesen des Oberharzes,' Stuttgart, 1895, p. 49.

[2] A. v. Koenen: 'Ueber die Dislocationen westlich und südwestlich vom Harz,' *Jahrb.* d. k. preuss. geol. Landesanst., 1893, pp. 68-82.

[3] K. Dalmer: 'Altenberg-Graupener Zinnerzlagerstätten,' *Zeit. f. Prak. Geol.*, 1894, p. 314.

periods of igneous activity of definite geologic age[1]. Thus in North America certain periods of deposition stand out prominently. His investigations show primary gold veins of (1) pre-Cambrian, (2) Mesozoic, (3) Tertiary ages[2].

Association of Certain Types of Veins with Particular Eruptive Rocks.

Since the oldest period of mining the miner has recognized certain eruptive rocks as carriers of ore. This is especially well known in the case of tin veins, associated with granite, as shown by the examples mentioned in an earlier part of this work, from the Erzgebirge, Cornwall, Malacca, Tasmania, etc.

Many other illustrations of such dependence have been furnished, especially by W. Möricke[3].

In Chile the gold-bearing copper veins are associated with moderately or highly siliceous eruptive rocks, such as quartz-gabbros, quartz-diorites, syenites, amphibole granitites, quartz-porphyries and rhyolites. Similarly in Hungary gold veins of diverse character are associated with Tertiary quartz-andesites (Verespatak, Nagyág, Boicza) or rhyolites (Königsberg near Schemnitz, Telkibanya). In California the gold quartz veins are in intimate relation to granitic rocks, as is also the case in the Ural region (Kotschkar, Berezovsk, etc.). They are also often found in connection with amphibolitized diabases (Australia, Mashonaland and Guiana).

Similarly in Chile the rich silver-copper veins are most commonly found associated with basic plagioclase-augite rocks, such as diabases, augite-porphyries, augite-andesites. Mention may be again made of the association of the Pribram lead veins with the diabases and diorites of that locality, as well as of the preference shown by the copper ores for melaphyres or diabase porphyries, as on Lake Superior. This subject has recently received much attention from Spurr and his critics[4]. Spurr has suggested that there are 'Metalliferous Provinces' as distinct and well defined as Petrographic Provinces, but not necessarily coincident with the latter.

[1] 'The Geological Features of the Gold Production of North America,' *Trans.* Am. Inst. Min. Eng., Vol. XXXIII, p. 790.

[2] Paragraph revised by translator.

[3] W. Möricke: 'Die Gold-, Silber- und Kupfer-Erzlagerstätten in Chile und ihre Abhängigkeit von Eruptivgesteinen,' Freiberg, 1897.

[4] 'A Consideration of the Igneous Rocks and their Segregation or Differentiation as related to the Occurrence of Ores,' *Trans.* Am. Inst. Min. Eng., Vol. XXXIII, p. 288. *Vide* Purington, 'Ore Deposits, a Discussion,' p. 68.

A REVIEW OF THE VARIOUS THEORIES OF THE ORIGIN OF MINERAL VEINS.

No other branch of geology has in former times yielded so great a number of theories and speculations as those upon the origin of mineral veins. These curious earlier hypotheses have been summarized by A. G. Werner[1] and later with greater detail by K. A. Kühn[2] and B. von Cotta[3]. They will not be discussed in detail, but brief mention will be given of Werner's views. According to him, mineral veins are formed by the filling of open fissures with chemical or mechanical precipitates from waters from above, or, as he expressed it, "from a wet solution mostly chemical, covering the region where the lode spaces existed, and at the same time filling the empty open lode spaces."

The various theories that sprung up during the time after Werner may be divided, as was done by Freiherr von Herder[4], into various groups, which we will now proceed to discuss.

It should be thoroughly understood, however, that all mineral deposits are not formed in the same way and are not explainable by a single theory. We will in each case enumerate the various groups of veins for which one or the other theory seems to us applicable.

(A) Congeneration Theory.

The old congeneration theory, according to which veins are not fissure fillings at all, but were produced simultaneously with the country rock, is now merely of historical interest. It becomes, however, debatable when modified by the clause "or the veins are parts of the rock masses subsequently changed by alteration," which corresponds to the views of J. F. W. Charpentier. In this sense many tin veins might perhaps be ranked under this head. Likewise the ore-segregations in eruptive rocks, which sometimes assume the form of lodes, as in the case of the bands (schlieren) of chromite ore, shown in Fig. 5, might be described as formed by congeneration.

(B) Descension Theory.

According to the descension theory veins are fillings of fissures which wedge out below. The vein filling came in from above and is quite independent of the nature of the country rock. This origin, as just noted, was applied by A. G. Werner to all mineral veins, and naturally greatly in-

[1] A. G. Werner: 'Neue Theorie von der Entstehung der Gänge,' Freiberg, 1791.
[2] K. A. Kühn 'Handbuch der Geognosie,' Vol. II, p. 666, Freiberg, 1834-36.
[3] B. v. Cotta: 'Erzlagerstätten,' 1859, Vol. I, part 2, p. 175.
[4] Freiherr von Herder: 'Der Tiefe Meissner Erbstolln,' Leipzig, 1838.

fluenced the views regarding the future of mining enterprises in mineral districts, for example, at Freiberg, since according to this theory the ore deposits would be confined to the uppermost part of the earth's crust. This theory, originating with so noted a man, was not vigorously opposed until, in 1840, Fr. von Beust[1] brought the opposition to a focus and upset the theory. The last adherent of the Werner theory in its general sense was Ch. Moore[2], who as late as 1869 applied this explanation to the veins of lead ore in the Carboniferous limestone of the Mendip and Alston districts in England, in which he affirmed that he had found Jurassic fossils.

True mineral veins really formed by solutions bringing material from above are probably very rare. The small stringers of rich copper ore found beneath the gossan in the Huelva pyrite deposits are of this class (see under Huelva). Their filling is derived from the pyrite decomposing to form the gossan, the rich copper ore being deposited from the solutions which seeped downward. In fact, the part of ore deposits near the outcrop often shows ore masses formed by descension, but these ores are purely of secondary origin, though sometimes of great economic importance. They have already been noted in describing the gossan of veins. Certain deposits of stalactic limonite found in veins may also be regarded as descension deposits. On the other hand, many barren veins actually exist which might justly be called descension veins.

C. G. A. v. Weissenbach[3] long ago mentioned sandstone and limestone veins formed in this way. All visitors to the Plauensche Grunde near Dresden are familiar with the narrow fissures seen in the syenite, which are filled with a breccia of shells determinable as Cenomanian. These crevices extend downward for about two meters below the surface of the syenite which forms the contact plane of the Upper Cretaceous. This class also includes the sandstone veins of California described by Diller[4] and those noted by Cross in the granite of the Pike's Peak region in Colorado; at both localities they represent earthquake fissures, probably filled by windblown sand. Oligocene sandstone veins have also been described by Pavlov[5] in the Neocomian clay of Alatyr in Russia, and Kalkowsky[6] in the

[1] F. C. v. Beust: 'Kritische Beluechtung der Werner'schen Gangtheorie,' Freiberg, 1840.

[2] Ch. Moore: '*Rep.* on Mineral Veins in Carboniferous Limestone and their organic contents.' *Rep.* of Brit. Assn. Adv. of Sc., 1869, p. 360 *et seq.*

[3] C. G. A. v. Weissenbach: 'Ueber Gangformationen, vorzugsweise Sachsens,' B. Cotta's 'Gangstudien', Vol. I, Freiberg, 1847, p. 17.

[4] J. S. Diller: 'Sandstone dikes,' *Bull.* of the Geol. Soc. of America, 1890, Vol. I, p. 411. Whitman Cross: 'Intrusive sandstone dikes in granite,' *Idem*, 1894, Vol. V, p. 225.

[5] A. P. Pavlov: 'Dikes of Oligocene Sandstone in the Neocomian Clays of the District of Alatyr,' *Geol. Mag.*, 1896, Vol. III, p. 49.

[6] E. Kalkowsky: 'Ueber einen Oligoc. Sandsteingang an der Lausitzer Ueberschiebung bei Weinböhla.' Abh. d. Isis, Dresden, 1897, 11, p. 80.

Turonian Pläner of Weinböhla in Saxony. In the last named case a little iron pyrite has been deposited in the center of the vein.

Similar veins due to the forcing in of soft rock material from above (gouge, clay, sandstone, particularly that carrying pebbles) occur in the main coal measure of the Plauensche Grunde near Dresden, as was known to von Weissenbach, and accurately described later by R. Hausse[1]. On account of their rough walls, whose tooth-like projections extend into the coal measures, the veins are called 'combs.'

Lastly true mineral veins sometimes show certain phenomena, which can only be explained by assuming a subsequent mechanical introduction of material from above.

In the Segen Gottes mine at Zwittermühl, in the upper Schwarzwasser Valley, in the Bohemian Erzgebirge, a cobalt vein was mined. Fifty meters east of the shaft, and 140 meters below the surface, the true filling between firm walls, at this point 0.6 meter apart, was washed out and replaced for a distance of 6 meters by coarse river drift passing upward into sandy material[2]. The river pebbles consisted of vein quartz, phyllite, quartzite and quartz-phyllite, such as occur in the normal drift of the Schwarzwasser, so that there can be no doubt of their having been introduced from above after the washing out of the soft gossan ores.

In the Diepenbrok mine near Muhlheim on the Ruhr (Selbeck mines) the vein is 0.5 to 8 meters thick, and consists mainly of zinc-blende, with some galenite and quartz, occurring in continuous pay streaks up to 600 meters long. Toward the beginning[3] of the 80's, on the 30-meter level at Dahm, a mass of pebbles and sand was encountered containing river boulders up to 10 quintals in weight, together with fragments of pine wood, and also, it is stated, the tooth of a mammoth. The drift consisted of clay slate and graywacke, in part also of fragments of vein matter rich in blende. This deposit of pebbles and sand form the filling of a gorge 262 ft. (80 m.) wide that was unknown until revealed by mining operations. The deposit ran at right angles to the strike of the lode, which there is about 1 meter thick. By excavation the débris was proved to extend 5 meters below the 30-meter level (that is to say, 5 meters below the bed of the Ruhr) without reaching its lower limit.

(c) Lateral Secretion Theory.

According to the lateral secretion theory the metallic and earthy contents

[1] R. Hausse: 'Profile durch das Steinkohlenbecken des Plauenschen Grundes,' Leipzig, 1892, p. 97.

[2] Note by A. W. Stelzner from letter of E. Treptow.

[3] Short communication of Dir. Rötzel to A. W. Stelzner.

of mineral veins are derived from the country rock, the material being chemically extracted from it by invading ground-water and redeposited in the vein fissure. This idea was expressed in the early works of Ch. T. Delius[1], C. A. Gerhard[2], and Lasius[3]. It was subsequently advocated by Bischof[4], and particularly by Forchhammer[5]. Bischof proved that the chemical compounds constituting the most common gangue are present in the country rock of the veins, and expressed the conjecture that even iron, manganese, and the other metals in our ores might be derived from the silicates of the country rock (*l. c.*, p. 720), and that probably the feldspar was in most cases the real carrier of the ore. Besides iron and manganese, Forchhammer also found in many rocks some zinc, nickel, cobalt, bismuth, lead, copper, silver and gold, and he referred especially to sodium chloride as the solvent of these metals. The theory was also supported by L. Dieulafait, who demonstrated the wide distribution of barium and strontium in all crystalline rocks[6], and ascertained also the presence of analyses[7].

Wallace[8], too, explained the origin of the ore lodes of Alston Moor by the decomposition and leaching out of the lead-bearing Carboniferous limestone by atmospheric water.

Finally Sandberger[9] adopted this theory and applied it to all possible ore deposits, basing his conclusions on numerous rock analyses made or collected by himself. Thus he referred the barite content of many lode fissures to the barium present in the orthoclase of granite and other rocks as previously ascertained by A. Breithaupt. The nickel ores of veins in the serpentinized paleopicrite of Nanzenbach he ascribed to the nickel content of the olivene in the fresh rock. According to him the heavy metals of the mineral veins in the gneissoid rocks of the Spessart and the Black

[1] Ch. T. Delius: 'Von dem Ursprung der Gebirge u. d. darinnen befind. Erzadern,' Leipzig, 1770.

[2] C. A. Gerhard: 'Beitrage z. Chem. u. Geschichte des Mineralreiches,' Berlin 1773-76.

[3] G. S. O. Lasius: 'Beobachtungen über die Harzgebirge,' Hanover, 1789-90.

[4] G. Bischof: 'Lehrbuch der chemischen und phys. Geologie,' 2d ed., 1863-71, Vol. III, p. 665 *et seq.*

[5] J. G. Forchhammer: 'Ueber den Einfluss des Kochsalzes auf die Bildung der Mineralien,' Poggendorf's *Ann.*, 1855, No. 5, p. 60.

[6] L. Dieulafait: 'Existence de baryte et de la strontiane dans toutes les roches primordiaires,' etc. 'Filons métallifères à gangue de baryte.' *Comptes Rendus*, Paris, Vol. LXXXVII, p. 934.

[7] L. Dieulafait: *Compt. R.*, Vol. LXXXVIX, p. 453. Vol. XCVI, p. 70. Vol. XCVIII, pp. 568, 634.

[8] W. Wallace: 'The Laws which regulate the disposition of Lead Ore in Veins illustrated by the mining districts of Alston Moor,' London, 1861.

[9] F. v. Sandberger: 'Zur Theorie der Bildung der Erzgänge,' *Berg u. Hutten Zeit.*, 1877, No. 44 *et seq.* *Idem.* 'Ueber die Bildung von Erzgängen mittelst Auslaugung des Nebengesteines,' *Z.* d. D. G. G., 1880, p. 350 *et seq.*

Forest are derived from the dark mica of that country rock, and the difference in the metallic content of that mica is reflected in the character of the ores of these two lode areas.

In point of fact, the lateral secretion theory seems applicable to many deposits, though it is not of the general application given it by F. von Sandberger.

The following examples of mineral veins are, in our opinion, really formed by lateral secretion:

The fissures in the Quader sandstone of Saxon-Switzerland are found very frequently lined with thin plates of manganiferous limonite, this same limonite also forming a cement in the adjoining quartz sandstone. Sometimes these plates form genuine stringer veins slightly worked in former times. As magnetite and other iron ores exist in small particles in this sandstone, as in most sands, a lateral secretion and subsequent segregation in the open fissure readily suggests itself. For that matter, the iron in various rocks is often concentrated in nodular concretions within the rock itself. Iron ore deposits originating in this way are also very common in ferruginous diabase tuffs, as, for example, those in the Lahn Valley. The manganese veins in hornblende porphyry at Ilfeld, in the Harz, also seem to have been formed in this manner. The fact that they usually become impoverished at so shallow a depth as 12 meters is itself evidence of their dependence on atmospheric seepage water.

The lateral secretion theory will also account for the veins and bunches of garnierite and other nickel hydrosilicate ores in serpentine. The olivene in the peridotite of Riddles in Oregon, for example, as mentioned on page 348, contains 0.26% of NiO, and the bronzite of the same rock 0.5% NiO. In the serpentinization of the olivene rocks of the Numea region of New Caledonia cobaltiferous manganese compounds, asbolite, etc., are apt to segregate together with the nickel hydrosilicates, though not in contact with them.

This theory is also applicable to other forms of epigenetic deposits. We have already referred to it in discussing the iron ores of the Marquette district on Lake Superior.

The iron, manganese and nickel ores of the deposits just mentioned are correctly ascribed to the decomposition and leaching of the country rock. The same is true, according to F. Sandberger[1], of a great number of other metals, the mica of the crystalline country rock being regarded as the original source of the heavy metals in the fissures.

[1] Summary by Carthaus: Sandberger's 'Erzgangtheorie,' *Zeit. f. Prak. Geol.*, 1896, p. 108 *et seq.*

According to Rammelsberg's terminology the mica formula is as follows:

$$m\,\overset{\mathrm{I}}{R}_4\,Si\,O_4,\ n\,\overset{\mathrm{II}}{R}_2\,Si\,O_4,\ v.(\overset{\mathrm{VI}}{R}_2)_2\,Si_4\,O_{12},$$ in which:

$\overset{\mathrm{I}}{R}$ = K, Na, according to F. Sandberger, also Li, Ag, H and Fl;

$\overset{\mathrm{II}}{R}$ = Mg, Fe, according to F. Sandberger, there is also Ca, Ba, Mn, Ni, Co, Cu, Pb, Zn;

$\overset{\mathrm{VI}}{R}$ = (Al_2), in some cases also (Cr_2).

$Si\,O_2$, sometimes partly replaced by $Ti\,O_2$ and $Sn\,O_2$.

The minute quantities of As and Sb found by F. Sandberger in many micas seem, according to him, to be combined as an acid. An entirely similar process will account, according to the same author, for the metals abundant in augite and hornblende.

The solution and leaching out of these metallic compounds was conceived by Sandberger to have been effected from above by seepage water containing acid alkalies and hydrogen sulphide. H_2S is taken up by many atmospheric waters through contact with decaying organic substances. The first results are soluble alkaline sulphides. These in turn are able to dissolve compounds of Sn, As and Sb, and to precipitate Fe, Pb, Zn, Cu and Ag as sulphides. The reactions produced by CO_2 and H_2S often take place in the presence of NH_4, formed by the decomposition of organic substances, of H_2SO_4, derived from the weathering of pyrite inclusions in country rock, and finally in the presence of organic acids, bases and salts.

The gangue minerals are supposed to originate in the same manner. Thus quartz results from the SiO_2 liberated by the decomposition of the silicates, barite from the barium in the feldspars, calcite from the lime of the feldspars, augites, hornblendes, etc., dolomite from the magnesia in micas, hornblendes and augites, fluorite from the F of the micas and hornblendes, the H_2SO_4 acting on potassium fluoride and the resulting solution, coming in contact with $CaCO_3$ producing CaF_2.

There is no doubt that the mineral contents of the seepage water (vadose) derived from the weathered materials above ground-water level by lateral secretion[1] does exert a great influence on the formation of secondary concentration of ore in the gossan zone (see p. 367), a general conclusion reached by Weed[2] and shown independently by Emmons[3] and Van Hise[4].

[1] This paragraph revised by translator.

[2] 'Enrichment of Ore Deposits by later metallic sulphides,' *Bull.* Geol. Soc. Am., 1900. 'Secondary Enrichment of Gold and Silver Ores,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXX, p. 424.

[3] 'Secondary enrichment of Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXX, p. 177.

[4] 'Principles Controlling Dep. of Ores,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXX, p. 73.

It is also possible that these ideas are applicable to certain primary orebodies of veins, but for the great majority of mineral veins they are untrue, as has been convincingly demonstrated by A. W. Stelzner. The fundamental error of this theory originated in the faulty analytical methods of F. Sandberger in tests made to determine the primary content of heavy metals in the country rock, and through his disregard of the secondary impregnation phenomena universally prevailing along vein fissures, whereby the metals characteristic of the lodes were enabled to penetrate far into the country rock. Stelzner's[1] investigations were carried on at two universally known mining districts, viz.: Pribram and that of Freiberg.

In the case of Pribram, F. Sandberger supposed the metallic contents of the mineral veins to come from the diabases accompanying them. Now, although his analyses actually show a lead and silver content in the diabase, yet this is only due to metallic material carried from the mineral veins into the country rock. F. Sandberger thought that if he decomposed the rock with hydrofluoric acid he would decompose all the silicates, but none of the particles of secondary ore, and if, therefore, he was able to demonstrate lead and silver in the solutions thus obtained, the metals thus found must have been chemically combined with the silicates that were dissolved by the hydrofluoric acid. F. Kolbeck and A. Schertel in Freiberg pointed out the flaw in this reasoning, and showed that hydrofluoric acid will also decompose galenite and other sulphidic ores. This demolished Sandberger's alleged proof of an original metal content in the diabase.

For Freiberg Stelzner[2] chose another method of investigation. With exceeding labor and care he crushed samples of the typical biotite-gneiss which forms the country rock of the veins, and, with the aid of the Thoulet and Klein solutions, separated out the various mineral constituents, collecting enough perfectly pure material of each mineral for analyses by competent chemists. As the rock samples consisted of perfectly fresh material, far from the zones of decomposition accompanying the veins, these analyses must show conclusively whether or not the metals characteristic of the Freiberg lodes were present in the silicates of the gneisses. It is not probable that such exceedingly accurate separations of the mineral constituents of rocks of complicated composition were ever made before. When it was found that despite this extraordinary care the mica thus obtained still enclosed particles of metallic sulphides, the problem was presented to the analyst by Stelzner in this form: "Show by test whether mica possibly containing inclusions of small quantities of metallic sulphides also contains

[1] A. W. Stelzner: 'Die Lateralsecretionstheorie und ihre Bedeutung für das Přibramer Ganggebiet,' B. u. H. *Jahrb.* der k. k. Bergak, Vol. XXXVII, 1889.

[2] A. W. Stelzner: 'Beiträge zur Entstehung der Freiberger Bleierz- und der erzgebirgischen Zinnerzgänge,' *Zeit. f. Prak. Geol.*, 1896, pp. 377-412.

metals in its own mass, that is to say, as original chemical constituents of silicates." The mica was, therefore, triturated with bromine and the pyrite particles leached out before the material was submitted to analysis. Among the results thus obtained we give the following by H. Schulze:

	Ludwigschachter Gneiss.	Brown Mica from Himmelsfürster Gneiss.	Wegefahrter Gneiss.
$Si\,O^2$	33.09%	34.28%	34.38%
$Ti\,O_2$	3.05 "	4.04 "	1.88 "
Al_2O_3	20.03 "	15.58 "	22.41 "
Fe_2O_3	2.85 "	15.67 "	12.66 "
$Fe\,O$	17.94 "	10.01 "	8.10 "
$Mn\,O$	0.26 "	0.42 "	Trace.
$Mg\,O$	8.70 "	9.52 "	9.48 "
$Ca\,O$	0.94 "	0.88 "	0.72 "
K_2O	8.88 "	5.58 "	7.13 "
Na_2O	0.48 "	0.42 "	1.56 "
Li_2O	Trace.	......	......
H_2O	3.75 "	2.75 "	2.02 "
F	......	......	......
$Sn\,O_2$	......	......	......
Insoluble residue	......	0.26 "	......
	99.97%	99.41%	100.34%
Heavy metals, according to Schulze	Ni, Co, Cu, Zn	Ni, Co, Cu	Ni, Co
Heavy metals, according to Sandberger	Ag, As, Pb, Zn, Co, Ni, Cu	Ag, As, Pb, Zn, Co, Ni, Cu, Sn	Ag, As, Pb, Zn, Co, Ni, Cu, Sb

The analyses of the feldspars of the Freiberg gneisses show a small amount of BaO and SnO_2, which can be used as an argument for a lateral secretion theory.

For example, according to H. Schulze, the orthoclase from the Ludwigschachter gneiss contained:

SiO_2	65.18%
Al_2O_3	18.44 "
Fe_2O_3	0.15 "
BaO	0.08 "
CaO	1.05 "
MgO	0.08 "
K_2O	13.33 "
Na_2O	1.64 "
SnO_2	0.03 "

While the oligoclase of the same rock held:

BaO	0.03%
SnO_2	0.08 "

Finally, the heavy metals were also found in the pyrrhotite, present in small amounts disseminated through the gneiss; 715 grams of Wegefahrter gneiss contained, according to A. W. Stelzner, 4.65 grams pyrrhotite, and this according to an analysis by H. Schulze gave:

Ni	0.61 per cent.
Co	0.12 "

From these and many other similar results of his careful investigations, A. W. Stelzner was able to show that the lateral secretion theory does not apply to the Freiberg ore lodes in any manner whatever, at least as regards the ores. In fact, the metals most characteristic for Freiberg, lead and silver, were not found at all in the silicates of the country rock, not even in traces, hence the relation of the nickel and cobalt content found in the pyrrhotite in the presence of this absolute lack of lead and silver is totally different from that which exists between these two ores in the Freiberg lodes. In the case of the latter, the proportions of the various metals, calculated from the actual metallic product of the mines is, according to Stelzner, as follows:

1 nickel, 731 silver, 85,679 lead, 2,198 copper, 3,259 zinc, 43,605 sulphur, 5,839 arsenic.

Hence, if the Sandberger theory were correct, these other metals ought to be present in the constituents of the gneiss in correspondingly greater amounts compared to the nickel. In view of these facts it must also appear very improbable that the BaO content of the feldspars of the gneisses furnished the material for the barite in the veins, and that the carbonates occurring in the Freiberg lodes are derived from the country rock.

In recent time the gold veins of Australia and New Zealand have also been studied and their ores tested with a view to ascertaining whether their origin might be explained by means of the lateral secretion theory. There, too, the result was negative. This important and thorough investigation was carried out by Don[1]. He tested over 400 samples of country rock from different depths, and at different distances from the lodes, for gold, silver and sulphides, using the surest and most refined methods. The gold was determined by the dry way, with specially purified lead, using in most cases more than two kilograms of rock material.

In no case did he succeed in demonstrating the presence of gold in rock that was free from pyrite and other sulphides, and in deeper zones, where both the lodes and the country rock were as yet undecomposed, the sulphides contained in the rocks did not, by any means, always contain gold. On the contrary, the gold content usually appears only in close proximity to the lodes, so that an immigration of the gold-bearing sulphides from the fissures can not *a priori* be denied. The conditions were somewhat different in the 'vadose' region in Posepny's sense, that is to say, *above* the ground-water level. There the gold content of the country rocks is not merely confined to the proximity of the lode, but extends much farther laterally and is at the same time much greater. Don explains this by the fact that the

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes,' *Trans.* Am. Inst. Min. Eng., 1898, Vol. XXVII, p. 564.

gossan is in constant formation and migrates downward during progressive denudation, causing a good deal of gold to pass into solution and to be redeposited in the decomposed country rock of these upper regions.

The principal solvent, according to Don, is chlorine. This, according to him, is formed as follows: The H_2SO_4 set free by the oxidation of sulphides combine with chlorides, forming HCl, and from this and the higher manganese oxides so common in the gossan the chlorine is developed. Free HCl was shown to exist in most fresh mine waters. The redeposition of gold is also proven by its occurrence inside of old mine timbers.

A weighty argument against the general application of the lateral secretion theory is the occurrence of veins of entirely different mineralogic and chemical character in the same rock; for example, in the homogeneous gneiss of the Freiberg district, lodes of highly varying type are found side by side; at Butte, Montana, the strongly contrasted types of copper and of silver veins occur in a mass of homogeneous basic granite. Conversely, one lode, or a number of similar lodes, traverse masses of very different rocks without showing any material change in the chemical nature of their filling, and frequently the same vein types recur in entirely different rocks. Thus at Freiberg the country rock of the pyrite-blende lead ores is gneiss; at Svenningdal, in Norway[1], it is limestone, with micaceous hornblende schist and granite.

The lateral secretion theory, as A. W. Stelzner has very fitly remarked, is not reconcilable with the presence of mineral crusts showing a successive deposition at a different time of the ore and gangue minerals filling the fissures. A progressive lateral leaching out of the country rock should result in a constant composition, or, at any rate, of a uniform character of the solutions passing into the vein fissures. Any general application of this theory is therefore decidedly impracticable.

(D) The Ascension Theories.

The various ascension theories assume that the material filling the vein fissures and impregnating the wall rocks rose from an unknown depth in three ways:

1. In a molten condition—the injection theory.
2. In the form of gases and vapors—the sublimation theory.
3. In solution in more or less heated water containing gases—the hydrothermal theory.

[1] J. H. L. Vogt: 'Silbererz,' etc., *Zeit. f. Prak. Geol.*, 1902, p. 8.

1. The Igneous Injection Theory.

The curious ideas advanced by A. Petzholdt[1] and J. Fournet[2], who ascribed the origin of mineral veins to injections of molten metalliferous matter coming from the remote depths of the earth, are now merely of historic interest.

The small veinlets of metallic sulphides formed artificially but unintentionally in the joints of an old furnace wall of the Muldner Works, near Freiberg, was supposed by B. von Cotta[3] to represent an example of a deposit formed according to this theory. These artificial veinlets are found in the gneiss of the furnace wall. The veins consist mainly of galena. The gneiss, moreover, was laterally impregnated with apparently perfectly isolated ore particles. Plattner, who also investigated these interesting artificial products, suggested very properly (it would seem) that sublimation rather than injection in the molten condition will probably account for their origin.

As will be shown farther on, the old injection theory has lately been resuscitated, being applied by Weinschenk to the pyrite deposit of Bodenmais.

2. The Sublimation Theory.

That certain ore deposits may be formed by sublimation is beyond doubt. Perfectly competent observers record the formation of hematite on lavas of recent age and in the craters of active volcanoes, often, indeed, within fissures. The following reactions explain the process:

$$2FeCl_3 + 3\,H_2O, \text{ both in the form of vapor,}$$
$$\text{give } Fe_2O_3 + 6H\,Cl.$$

This mode of origin of minerals through reactions of various *gases and vapors on each other* is designated, after Bunsen, by the term *pneumatolysis*.

Sublimation products having all the properties of natural ores are also sometimes formed during the roasting and smelting processes of our metallurgic furnaces; for example, artificial galenite, zinc-blende, realgar, etc. Finally, quite a number of other ores may be experimentally produced by sublimation, with exclusion of air, etc.

Durocher[4] was one of the principal champions of a general application of

[1] A. Petzholdt: 'Erdkunde.' Leipzig, 1840.

[2] J. Fournet: 'Vereinfachung der Lehre von den Gängen.' Freiberg, 1846. Translated from French into German by H. Müller.

[3] B. v. Cotta: 'Ueber Erzgänge in einer Flammofensohle.' Gangstudien, II. Freiberg, 1854, pp. 1–19.

[4] Durocher: 'Production artificielle, par voie sèche, des principaux minéraux contenus dans les gîtes métallifères.' *Comptes Rendus*, Vol. XXXII, 1851, p. 823; Vol. XLII, 1856, p. 850.

the sublimation theory to ore deposits. He thought that the inequality in the distribution of the ores in lodes could be best explained by assuming that they were deposited from gaseous currents. He tried to explain this theory experimentally by passing metallic vapors through heated glass tubes and thus producing deposits of various sulphidic ores.

A limited application of the sublimation theory to the veins of tin ore was made by A. Daubrée[1], and to this extent the theory still has many adherents. Daubrée pointed to the stability of tin fluoride at high temperatures, and assumed that the tin in this form rose from the depths of the granitic magma hearths during or immediately after the granitic eruption, and was accompanied by boron and fluorine compounds, for example, silicon fluoride, as well as gaseous chlorine and phosphorous compounds. He based this hypothesis on the extensive participation of fluorine, boron, chlorine and phosphorus in the composition of the gangues characteristic of the tin ore formation (page 200). As a further proof he produced cassiterite experimentally from volatile compounds. For this purpose, it is true, he did not use tin fluoride, but placed the entirely analogous tin chloride in a porcelain tube heated to white heat, through which he passed vapors of tin chloride and water. He actually obtained hydrogen chloride and small crystals of cassiterite. The process takes place according to the formula:

$$SnCl_4 + 2H_2O = 4H\ Cl + SnO_2.$$

In an entirely analogous way we may imagine:

$$SnF_4 + 2H_2O = 4HF + SnO_2.$$

A similar experiment gave:

$$TiCl_4 + H_2O = 4HCl + TiO_2$$

This last experiment led A. Daubrée to apply the theory of pneumatolysis also to the veins with titanium minerals such as are found, for example, in Dauphiny.

These ideas are strongly supported by the demonstration of the existence of corresponding metallic compounds in the fumaroles of existing volcanoes. Thus, according to A. Bergeat, the deposits of the fumaroles of the island of Vulcano were demonstrated by A. Cossa to contain almost all the elements characteristic of the tin deposits: boran and fluorine, besides lithium, tin, bismuth, copper, phosphorus and arsenic[2].

That the deposition of tin oxide is possible in nature in a purely aqueous way, even at ordinary temperature and under normal atmospheric pressure, is proved by the occurrence of fragments of stags' antlers in the tin ore placers of Cornwall, the organic substance in these fragments being, accord-

[1] A. Daubrée: 'Mém. sur le gisement, la constitution et l'origine des amas de minerai d'étain.' *Ann. des Mines*, 3d series, Vol. XX, 1841, p. 65.

[2] A. Bergeat: 'Die äolischen Inseln.' *Abh.* Akad., Munich, 1899, vol. XX. p. 193.

ing to J. H. Collins[1], partly replaced by tin oxide. Moreover, tin oxide occurs in many mineral waters, notably in the warm spring or Ajer Panas in Selangor on Malacca, where the siliceous sinter deposited by the spring contains, according to St. Meunier, the following substances:

Silicic acid	91.8	per cent.
Water	7.5	"
Tin oxide	0.5	"
Iron oxide	0.2	"

Notwithstanding these facts, all the phenomena discussed in treating of intrusive stocks of granite strongly support Daubrée's assumption of deposition by metalliferous, gaseous and vaporous exhalations during and immediately after the intrusion of the granitic magma. However, it would certainly be wrong to assume that the minerals of tin veins owed their origin to steam alone; the facts show it to be by a mixture of heated solutions and steam. We even think that the former must have been by far predominant. The formation of such vast tin deposits as, for example, those of Zinnwald, described previously, with their druse-lined cavities into which quartz crystals projected, some of them 30 centimeters long. distinctly indicates that there must have been a segregation from solutions. The numerous fluid inclusions in the topazes, tourmalines, quartzes, etc., of the tin ore lodes are also most naturally explained by this assumption.

It is shown elsewhere[2] that even after the formation of the tin-bearing impregnation fissures in the periphery of the granite stock of Zinnwald, later intrusions of the granitic magma took place, as clearly proven by the small veins of fine-grained, but slightly micaceous granite traversing those zwitter stringers in the quartz porphyry of Teplitz. This fact is also good ground for the belief that the development of the tin veins and impregnations was a direct accompaniment of the granite intrusion, and that, therefore, there is nothing opposed to the assumption of deposition by vaporous exhalations, together with overheated water given off by the hot magma.

In former times quicksilver deposits were believed to be due to sublimation as first advanced by Lasius[3]. The observations made on the quicksilver deposits of California (see p. 359) demonstrated the falsity of that theory for this class of ore deposits.

Deposition from sublimation was formerly suggested to explain the origin of certain gold veins. The occurrence of native arsenic, for example, on the lower side of rhodochrosite crystals, lying transverse to the selvage in

[1] J. H. Collins: 'Cornish Tin-Stones and Tin-Capels.' *Mineralog. Magaz.*, 1882, Vol. IV, p. 115.

[2] R. Beck: 'Einige Beob. im Gebiete der Altenberg-Zinnwalder Zinnerzlagerstätten,' *Zeit. f. Prak. Geol.*, 1896, p. 148.

[3] G. S. O. Lasius: 'Tagebuch einer Reise in die Gegend der Pfälzischen Quecksilberberge, in Born-Trebra.' Bergbaukunde, 1790, Vol. II, p. 353.

the gold veins of Nagyág, it was thought could be explained only by sublimation. Even Richthofen[1] assumed at that time that the gold veins in the propylites of Hungary and North America were formed by sublimation during a kind of solfatara activity in the eruptive centers of those regions. All the phenomena observed in this field favor the *hydrothermal theory,* which will now be discussed.

3. Hydrothermal Theory.

Freiberg has long been the radial point for the theory that mineral veins were produced essentially by deposition from rising thermal waters, the infiltration theory, as it was generally called in earlier days, the hydrothermal (or thermal) theory, as it is now universally and more fairly designated. The theory was first placed on a firm scientific basis through the work of F. C. von Beust, H. Müller, Th. Scheerer, B. von Cotta and A. W. Stelzner. It has since been carried all over the world by the numerous disciples of the two authors last named.

This theory originated, however, in France, where E. de Beaumont[2] was the first to advance detailed arguments in favor of the connection between mineral vein formation and the highly heated interior of the earth. According to him the lodes owe their origin to volcanic emanations, consisting of hot liquid injections, vaporous sublimations and watery infiltrations. From that time these views maintained their supremacy in France, and formed the key note of the great works by A. Daubrée, 'Les eaux souterraines aux époques anciennes,' and by E. Fuchs and L. De Launay, 'Traité des Gîtes Minéraux et Métallifères' (1893). This theory was also vigorously advocated by Th. Kjerulf and the Scandinavian school of geologists influenced by him. Its most positive expression, however, was doubtless given to it in the intensely suggestive work of F. Posepny[3], 'On the Genesis of Ore Deposits,' which first appeared in English in 1893. In North America the ground was prepared and ready for the acceptance of the most extreme view of the thermal theory as presented in Posepny's 'Genesis,' for at an early date J. S. Newberry[4] and other eminent economic geologists had declared themselves its adherents.

[1] F. v. Richthofen: 'Studien an den ungarisch-siebenbürgischen Trachytgebirgen.' *Jahrb.* d. k. k. geol. Reichsanst., 1860, p. 275.

[2] E. de Beaumont: 'Ueber die vulkanischen und metallischen Emanationen oder Ausströmungen,' translation in B. v. Cotta's Gangstudien I, Freiberg, 1850, p.p 329–436, out of *Bull.* de la Soc. Géol. de France, 2d Ser., Vol. IV, p. 1249, *et seq.*

[3] F. Posepny: 'On the Genesis of Ore-Deposits.' *Trans.* Am. Inst. Min. Eng., Chicago Meeting, 1893, Vol. XIII, p. 587, *et seq.* Second edition, with addition of other important works on this subject. New York City, 1902. Pub. by the Inst.

[4] J. S. Newberry: 'The Origin and Classification of Ore Deposits.' New York, 1880.

Its real victory may well be said to have begun only when A. W. Stelzner inflicted his destructive defeat of the lateral secretion theory as enunciated by Sandberger. In his last posthumous essay relating to this scientific battle Stelzner concluded with the following words:

"From all this it appears that the actually observed conditions can only be satisfactorily explained by the assumption that the solutions filling the fissures were not derived from the surface waters, but were spring water; that they were chemically and physically different at different places, and perhaps at different times, and that the substances deposited by them in vein fissures were for the most part brought up by them from the depths and only to a slight extent leached out of the rock bodies traversed by these fissures[1]."

This statement of the hydrothermal theory will form the basis for further discussion.

The hydrothermal theory in common with the lateral secretion theory maintains that the material of the veins, with the exception of wall rock introduced mechanically, was deposited from aqueous solutions. This supposition is entirely unobjectionable, since the solubility of all ore and gangue minerals in waters containing carbonic acid and other gases is an established fact, accepted since the famous investigations of G. Bischof. Furthermore, the formation of pseudomorphs and the structure of mineral crusts are important evidence on this point. The same testimony is given by the frequent inclusions of fluids in vein quartz and other vein minerals. Such liquids are even carried by the ores themselves, as may be observed in transparent zinc-blendes and proustite.

A great point in favor of the hydrothermal theory is the fact that the waters and deposits of existing hot springs contain both the metallic and non-metallic elements which compose the essential constituents of the ores of mineral veins. A careful and detailed summary of such occurrences has been given by G. Bischof[2], and since then our knowledge has been largely increased, as shown by the summaries of J. Roth[3] and L. De Launay[4]. From the rich fund of observed material on hand we will borrow only a few facts, taken mainly from De Launay's work:

It has long been known that numerous hot springs contain sulphur either in the form of hydrogen sulphide or as sulphates and sulphides of alkaline earths, and more rarely of metals, and carbonic acid in both the

[1] *Zeit. f. Prak. Geol.*, 1896, p. 412.

[2] G. Bischof: 'Chem. u. Phys. Geol.' 1st ed., 1847, Vol. II, p. 2079, *et seq.*; 2d ed., 1866, Vol. III, pp. 904—912.

[3] J. Roth: 'Chem. Geol.,' Vol. I, 1879, p. 564, *et seq.*

[4] L. De Launay: 'Recherche, Captage, et Aménagement des Sources Thermo Minerales,' Paris, 1899, p. 85 *et seq.*

free and combined condition. Chlorine compounds are frequently found. Bromine combined with alkalies is known to exist in the thermal springs of Nauheim, Iodine at Vichy. Fluorine exists in the springs of Carlsbad, Plombieres, Vichy and others; phosphoric acid in the two last named.

Arsenic is found abundantly in the hot waters of the Yellowstone Park geysers and hot springs (0.003 grams per liter or 0.3 grams sodium arseniate per gallon), and in the thermal springs of Bourboule (0.0155 grams of sodium arseniate to the liter). Boric acid is known from several geysers and hot springs of the Yellowstone Park, as well as in the thermal springs of Sulphur Bank and Steamboat Springs in western North America, as is described in greater detail in subsequent pages. Its presence has been demonstrated at Salies and in several other thermal springs of the Pyrenees; at Tarasp and Sanct Moritz; at Friedrichshall and Homburg, and in the hot waters of the copper mine of Boccheggiano (p. 428). From the springs of Salies boric salts were obtained. Not only is silica found in the boiling waters of true geysers, but it occurs in the thermal springs of Plombieres, Carlsbad and many other localities. Titanic acid is mentioned from the boiling springs of Pyrmony and from Carlsbad. Sodium, potassium, calcium, magnesium and aluminum are extensively distributed. Lithium is contained in the waters of Vichy, Bourboule and Ballardvale, and many other springs. To complete this list we will add that traces of rubidium and caesium occur in the spring waters of Carlsbad, Vichy, Bourbon and elsewhere. Barium and strontium are present, for example, in the springs of Ems (0.0028 grams per liter) and of Carlsbad. A spring near Lautenthal, in the Harz, flowing 40 liters per minute, deposited 2,000 kilograms of barite in the brief space of 3 to 5 years. Iron and manganese are present very often, the former sometimes in great abundance. Traces of chromium are contained in the deposits of the hot springs at Carlsbad. Nickel is known from Ronneby in Sweden, cobalt from Lamalon (Hérault), zinc from Pyrmont, tin from Kissingen and elsewhere, copper from Bruckenau, Rippoldsau and Sanct Moritz. Lead does not seem to have yet been proved with certainty. Traces of gold are mentioned from Carlsbad. Its presence in thermal springs is proved by a specimen of decayed wood in the hot springs of Taupo on New Zealand, in which Liversidge discovered gold-bearing pyrite and in the pyrite deposited in fissures in rhyolite by the waters of the Monarch Geyser, Yellowstone Park, as discovered by Weed. Antimony occurs at Pyrmont and Steamboat Springs, Nevada; quicksilver in several thermal springs in California (see later). Silver occurs in the deposits of the Boulder Hot Springs, Montana. Gold and silver to the value of $15 per ton occur in sinter of the Ohaeawai Hot Springs, New Zealand.

Still more conclusive evidence than this presence of metals in many thermal springs is afforded by the further fact that many thermal springs even now flow in mineral veins. This was first set forth in detail by Daubrée[1] and by Müller[2].

At Plombieres, in the southern Vosges, numerous mineral springs issue from the granite in a zone 220 meters long and 70 meters wide. The temperature of the hottest is 73° C., and that of the others only 15° to 30° C. Among their chemical constituents, which amount to but 0.03 grams per liter, potassium silicate predominates. When excavations were made in the granite about the so-called "soapy" springs in order to enclose them, several veins of quartz and fluorspar were traversed and the same minerals were found impregnating the adjoining granite, as well as the lower layers of variegated sandstone which overlie it. Besides the minerals named the veins also carried some barite, iron pyrite and red hematite. The thermal waters rise along the walls of these veins. That these deposits are still forming in fissures is proved by crystals of fluorspar in the midst of the Roman walls, as well as by a series of interesting newly formed minerals produced by reactions between the compounds contained in the thermal water and the ingredients of the concrete used by the Romans. In the cavities of the bricks bound together with lime mortar, zeolites, especially apophyllite and chabasite, have crystallized out, accompanied by opal and aragonite. A much greater variety of newly formed minerals was encountered, according to A. Daubrée[3], in cleaning out an old Roman well on a thermal fissure at Bourbonnes-les-Bains. The thermal water acting on accidentally introduced gold and silver coins, pieces of lead, bronze statuettes, iron objects, and the like, since their introduction in Roman time, had led to the segregation of quite a series of ores, such as galenite, phosgenite, anglesite and cerussite, as well as cuprite, chalcocite, chalcopyrite, bornite, tetrahedrite, atacamite, and finally iron pyrite and a siliceous oxidation product of iron.

Out of numerous examples tabulated by Müller a few may suffice:

According to H. Müller, the thermal springs of Wiesenbad and of Wolkenstein, in the vicinity of Annaberg, rise from drusy quartz lodes which in places carry barite. In the Churprinz, Friedrich August Erbstolln, at Grossschirma, north of Freiberg, barytic lead veins in biotite gneiss were formerly worked (see p. 258). In one, the Ludwig Spat, in 1821, about 160

[1] A. Daubrée: 'Mém. sur la relation des sources thermales le Plombières avec les filons métallifères,' etc. *Ann. d. Mines.* V. Ser., Vol. XIII, Paris, 1858, pp. 227–256.

[2] H. Müller: 'Ueber die Beziehungen zwischen Mineralquellen und Erzgängen im nördlichen Böhmen und in Sachsen.' B. v. Cotta's Gangstudien, III, Freiberg, 1860, pp. 261–309.

[3] A. Daubrée: 'Experimental Geologie,' Paris, 1879, pp. 71–102.

meters below the surface, a mineral spring was tapped having a temperature of 29.5° C., and rising in especial abundance at intersections of cross fissures. Chemical analyses showed it to be acid with sulphates of the alkaline earth and to hold free carbonic acid and to be almost entirely free from iron.

Mention may also be made of the thermal spring reported by F. Laube, having a temperature of 28° C., which was tapped at a depth of 331 m. (1,085 ft.) in 1864 in the Geschieber lode at Joachimsthal in the Bohemian Erzgebirge.

A very remarkable hot spring was tapped in 1901 in the copper vein of the Boccheggiano mine (see p. 267) near Massa Marittima, Tuscany. Its temperature was 40.6° C. According to an analysis by Fresenius, reported by the mine management, one liter of the hot water contained:

Sulphuric acid	0.3100 grams.
Silicic acid	0.0232
Boracic acid	0.0073
Chlorine	0.0179
Carbonic acid (combined with bases)	0.0771
Lime	0.2718
Magnesia	0.0271
Ferric oxide	0.0035
Potash	0.0288
Soda	0.0060
	0.7727

To refute these and other facts, F. Sandberger pointed out that most thermal springs leave deposits only on the earth's surface, but do not produce true quartz formations in their channels of exit. This objection is overthrown by the occurrence in western United States of hot springs which show deposits of metallic sulphides and other compounds in the fissures of active springs. The Ohaeawai Hot Springs of New Zealand are similar[1].

At Steamboat Springs, in Nevada (6 miles from the well-known Comstock Lode) the substratum is formed of granite covered by Juratrias beds, and is intruded by andesites and basalts. Carbonic acid and some hydrogen sulphide issue from the ground, and there are several thermal springs with a temperature of 75° C. (167° F.)

In the siliceous sinter of the basin of Steamboat Springs metallic sulphides are found. A piece of sinter colored red by metastibnite (Sb_2S_3) and weighing 3,403 grams contained:

Gold	0.0034 grams.	Silver	0.0012 grams.
HgS	0.0070 "	PbS	0.0720 "
Cu S	0.0424 "	Fe_2O_3	3.5924 "
$(Sb, As)_2S_3$	78.0308 grams.		

[1] A. P. Griffith: *Trans.* New Zealand Inst. Min. Eng., Vol. II, p. 88.

According to G. Becker, 10 liters of the thermal water of Steamboat Springs contained:

$FeCO_3$	0,0029 grams.	$NaCl$	14,1475 grams.
$MgCO_3$	0,0099 "	KCl	1,9735 "
$CaCO_3$	0,1577 "	Na_2SO_4	1,1147 "
$NaHCO_3$	2,9023 "	Li_2SO_4	0,5650 "
Na_2CO_3	0,4313 "	$Na_2Bo_4O_7$	3,1368 "
$Ca_3P_2O_8$	0,0137 "	$Na_2Si_4O_9$	3,9090 "
Al_2O_3	0,0025 "	Na_3SbS_3	0,0100 "
$NaHS$	1,1147 "	Na_3AsS_3	0,0866 "
nNa_2S, HgS			Traces.

A tunnel into the hillside at Steamboat Springs cut one of the older hot spring fissures at a depth of 50 feet below the surface. This fissure contained quartzose veinstone carrying crusts and coatings of cinnabar.

Recent excavations have shown that the waters are encrusting and cementing together the pebbles of the old stream gravels with pyrite and stibnite[1].

Equally weighty evidence is furnished by the phenomena seen in mines at Sulphur Bank, in the Coast Range of California[2]. The deposit was at first quarried for sulphur. At a shallow depth the sulphur gave out, but in its place rich cinnabar ores made their appearance, both in fissures and as an impregnation of the completely decomposed rock. This rock consisted of sandstones and slates, often comminuted into a breccia and covered by a basalt sheet. Hot waters and gases emerge from the cinnabar-bearing fissures and rendered mining so difficult that work had to be abandoned as the depth became greater. Besides cinnabar, pyrite and opal are also deposited by the thermal water. The deposit of silicic acid is found in all possible stages of hardening, from a gelatinous condition to that of chalcedony, and alternates with crusts of cinnabar and pyrite. The temperature of the water was 80° C. (176° F.) The chief constituents of the salts, which occur in extraordinary amounts, are chlorine compounds, borax and double carbonate of sodium. The gases given off and in part held in the water have the following composition: in 1,000 parts, 893 parts of CO_2, 2 parts of H_2S, 79 parts of CH_4. and 25N, besides traces of ammonia. The pyrite of the deposit contained small quantities of gold and copper.

Finally a most instructive case is that of the hot springs at Boulder, in Montana, described by Weed[3]. The fissures, some of which are still filled by hot water, contain deposits of chalcedony, jasper, quartz and calcite, as well as of stilbite. The springs deposit practically no surface sinters.

[1] W. Lindgren: 'The Occurrence of Stibnite at Steamboat Springs, Nev.,' *Bull* Am. Inst. Min. Eng. No. 2, March, 1905, p. 275.

[2] G. Becker: 'Quicksilver Ore Deposits of the Pacific Slopes.' *Monogr.* U. S. Geol. Survey, XIII, 1888.

[3] W. H. Weed: 'Mineral Vein Formation at Boulder Hot Springs, Montana.' 21st *Ann. Rep.* U. S. Geol. Survey, 1900, part II, pp. 227-255.

The granite alongside the veins is decomposed, the feldspars and quartz, hornblende and biotite having been altered to sericite and kaolin. Both this altered wall-rock and the vein filling contain small amounts of the precious metals, namely, up to 1.5 grams of gold and up to 12.4 grams of silver per ton.

A consideration of the thermal theory leads to the question: Where does the uprising thermal water come from? Is it derived from the atmospheric waters which have seeped down from the earth's surface (*vadose* region of F. Posepny) into the greatly heated depths (*profound* region of the same author), where it has gathered into large fissures, and returns, or is it the watery vapor given off by molten magmas?

A. Doubrée[1] thought that the first hypothesis answered this problem when he proved, by continuing the experiments of Jamin, that the force of capillary attraction accounted for the seeping in of atmospheric water along capillary fissures of rocks even down to the deep-seated zones of hot rocks and despite the counter pressure acting from below caused by the great development of heat in the deeper regions. That when this seepage water encountered fissures, to which the laws of capillarity do not apply, this now heated water returns to the surface in the form of a thermal spring or of vapor. He assumed that this may even explain explosions of steam and other volcanic phenomena. F. Posepny[2] applied the results of these experiments especially to the hydrothermal theory, and formulated his view in the following sentences:

"There is a descent of ground-water through the capillaries of the rock, even in the profound region. Having arrived at a certain depth it is probable that a lateral movement takes place toward the open channels. Having reached these it returns, ascending to the surface."

In opposition to this[3], Kemp has recently expressed doubts whether Daubrée's experiment can really be applied to the conditions in the interior of the earth, where the capillary force does not act against an empty space, as in the experiment. Kemp[4], moreover, pointed to the fact that in the deep works of several mines nothing is observed to indicate any general deep seepage of water in the rock; that these works even suffer from great dryness, as in the Calumet mine, Michigan, in the Adalbert shaft of Pribram, and in some deep works at Freiberg, and finally that many deep borings reach perfectly dry rocks. Ed. Suess[5], too, has recently expressed himself strongly

[1] 'Geologie Experimentale,' p. 236.
[2] 'Genesis of Ore Deposits,' p. 38.
[3] This and the four following paragraphs have been revised by the translator.
[4] 'Genesis of Ore Deposits,' p. 688, *Trans.* Am. Inst. Min. Eng., 1903.
[5] *The Engineering and Mining Journal*, Vol. LXXVI, 1903, pp. 8, 52.

against Daubrée's idea. The thermal springs, such as are concerned in the formation of most ore lodes, began merely by "juvenile springs," as they are called by that author, that is to say, springs which "rise from the depths of the globe as after-effects of volcanic activity and whose water comes to the light of day for the first time."

Whether this or the other view of the hydrothermal theory be adopted, it is certain that the mineral substances carried by hot water from below intc vein fissures are in the main derived from the deeper regions of the earth. The water, in passing through those heated deep-seated regions, may have leached the mineral matter out of the rocks prevailing there, for it is well known how the solvent power of water is increased by high temperature.

This latter view accords with the *leaching out theories* of several American investigators, especially Emmons and Becker. They suggest that the material filling the veins was leached out by hot spring waters, not, indeed, from the immediate country rock of the ore-bearing fissures, but from rock masses situated farther away and in most cases at greater depth, especially from eruptive rocks[1]. Emmons discussed this view first with regard to the Leadville deposits[2]. Becker[3], writing of the thermal waters of Steamboat Springs and Sulphur Bank, assumed that the metallic compounds contained therein were leached out by water from the masses underlying the granite and also from the granite itself. H. Louis[4] justly remarks that there is no essential difference between this kind of a lateral secretion theory and the hydrothermal theory.

The clearest expression of this compromise form, so to speak, of the ascension or hydrothermal theory, was given by J. Le Conte. He opposed the view of F. Posepny that the thermal springs bring the metals up with them from the barysphere, that is to say, from the core of the earth, which, according to a plausible hypothesis[5], is very rich in heavy metals. Le Conte is of the opinion that the lower boundary of water circulation may possibly be reached at a depth of 8 or 10 miles. But in the thermosphere, which also has quite a high temperature, the springs, he thinks, would have sufficient opportunity to leach from the rocks the metallic compounds scattered through them in small amounts, and thus to concentrate them afterward in higher zones.

[1] For a clear statement of this theory see Emmons's Presidential Address, *Bull.* Geol. Soc. Amer., Vol. XVI, pp. 1–28.

[2] 'Genesis of Certain Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1886, Vol. XV, p. 125.

[3] 'Geology of the Quicksilver Deposits of the Pacific Slope,' *Monogr.* U. S. Goel. Surv., 1888, p. 449.

[4] H. Louis in Phillips-Louis treatise on 'Ore Deposits,' 1896, p. 136.

[5] This is affirmed by Vogt to be untenable. *Trans.* Am. Inst. Min. Eng., XXXI, p. 126.

An amplification and a very clear statement of Le Conte's ideas is given by Van Hise, whose work has already been cited. In a general way he attributes most ore deposits to *descending water,* giving it a much greater part in the deposition of ores than his predecessor just named. An excellent review of the entire subject is given by Emmons in his 'Theories of Ore Deposition Historically Considered[1].'

While we recognize that descending atmospheric water is an agent of great importance in the redeposition and further concentration of ores in the upper parts of mineral veins, yet we maintain that the original formation of most ore lodes is due to *thermal water rising from great depth. These thermal waters are believed to be the after-effects of Plutonic eruptions, such as the intrusion of granitic masses;* also of volcanic events in the narrower sense. This conviction is strongly supported by the close relation, so often pointed out in this work, between mineral veins and eruptive rocks—a relation finding more and more general recognition[2].

V. EPIGENETIC ORE DEPOSITS IN STRATIFIED ROCKS.

Exclusive of Veins.

It has been repeatedly pointed out in the preceding chapter that metalliferous waters not only formed deposits in fissures, but also penetrated in many instances into masses of stratified rocks and enriched them with ores. The manner of this mineralization is exceedingly varied.

In a number of instances the solutions simply filled the interspaces between the grains or crystalline constituents of rocks, completely saturating the entire strata and eventually leaving ore and non-metallic minerals in the pores. In most cases, however, the solution saturating the rock also attacked it chemically, etching and even dissolving certain constituents, whose place might thereupon be filled by particles of ore minerals. If the metalliferous solutions encounter readily soluble carbonate rocks, limestones or dolomites, calcareous slates, marls, etc., this replacement prevails to an important extent, being usually, it is true, accompanied by another process, namely, the filling of the pre-existing larger cavities in such rocks. The cases in which such fillings of cavities in limestone occur alone are probably quite rare, and are in such instances closely connected with the filling of vein fissures.

It is difficult to marshal this multitude of varied phenomena into any orderly arrangement, or to group them comprehensively, since sharp bound-

[1] *Bull.* Geol. Soc. Am., 1904, Vol. XVI, pp. 1–28.

[2] See Kemp: 'Rôle of the Igneous Rocks in the Formation of Veins,' *Trans.* Am. Inst. Min. Eng., Vol. XXXI, Feb., 1900. J. E. Spurr: 'A Consideration of Igneous Rocks,' etc. *Trans.* Am. Inst. Min. Eng., Vol. XXXII, Feb., 1902.

aries between the several categories do not, as a fact, exist in nature. Yet it is advisable, for practical reasons, that such a grouping be attempted, although it is realized that it can never be free from inconsistencies. In so doing we adopt as criteria for this separation into groups: 1st, the nature of the country rock; 2d, the shape of the deposits, at least to a certain extent, and accordingly establish the following divisions:

A. Ore deposits which are of distinctly stratum-like form, due essentially to an impregnation of non-calcareous rocks; briefly designated as *epigenetic orebodies.*

B. Ore deposits mostly in the form of pockets, masses, 'chambers' or 'chimneys,' formed essentially by the metasomatic replacement of calcareous rocks; in brief, *epigenetic ore stocks.*

C. Ore deposits mostly stock-like or tube-like in form, due essentially to a simple filling of pre-existing cavities; in brief, ore-bearing *cavity fillings.*

It will furthermore be convenient to separate and treat separately from the two first mentioned groups a series of deposits which do not indeed differ much from the others in form or structure, but differ greatly in mineralogic composition and genesis, namely, the *contact metamorphic deposits.* A more accurate characterization of them will be given later on.

A. EPIGENETIC ORE DEPOSITS.

(a) In the Crystalline Schists.

At the head of this group we put certain deposits whose ore is probably only in part of indigenous origin, and which thus represent a transition connecting this class with the syngenetic deposits already discussed. These deposits are furthermore distinguished by the presence of associated oxide and sulphide ores, while the great majority of this group of ore deposits contain, aside from the gossan, only sulphide ores.

Epigenetic Deposits of Oxides and Sulphides.

1. *The Ore Deposits of Schwarzenberg, Saxony.*

In the vicinity of Schwarzenberg, in the western Erzgebirge, a dome of gneiss (augengneiss) is the basal formation. This is overlain on all sides by a mantle of mica schist, overlain to the north in turn by conformable beds of Silurian age (phyllite) and terminated on the south by a displacement. The center of this great anticlinal is pierced by a granite stock seen at Galgenberg and Rackelmann, near Schwarzenberg. This intrusion is one of a series of about 20 granite stocks aligned from southeast to northwest. The line runs parallel to and just east of the edge of the great

Eibenstock-Neudeck 'massif' of granite, which has altered the rocks by contact metamorphism for a great distance from its borders. The orebodies occur intercalated in these contact-metamorphic mica-schists, being found in an upper and a lower horizon. As the rocks encircle the granite, the orebodies form two concentric ring-shaped zones around the gneiss dome.

The ore deposits always occur either in close connection with crystalline limestones and dolomites, together with a rock consisting essentially of light green pyroxene (salite) and actinolite (the rock being analogous to the Swedish skarn), or the ores form subordinate intercalations in the mica schists (for the most part garnetiferous muscovite schist and gneiss-mica schist). In exceptional cases, as at Schutzenhaus and Forstwald, near Breitenbrunn, a limestone bed ("graue Flösse") rich in siderite occurs between the ore-bearing actinolite bed and the limestone bed ("weisse Flösse").

The real substratum of the ore is always the salite-actinolite rock, which nearly always contains garnet, quartz (often as green prase filled with microscopic needles of actinolite), calcite, pistazite, chlorite, green mica and fluorite, more rarely brownspar, manganite, feldspar, axinite, tourmaline, titanite, apatite, vesuvianite and helvite.

Magnetite not infrequently occurs in layers or even in entire beds, alternating with the salite-actinolite-rock or the limestone, and rarely as a cement between corroded grains of salite and garnet. Some of the deposits were for a while worked as iron mines exclusively, the altered ore of the outcrop being composed of hematite and limonite.

A different condition prevails among orebodies of the other metals, and the deposits may be divided into two groups.

One group consists of pyritous-blendic-lead-deposits, whose general characters correspond to the veins of this class already described. In the present case the ore is found to be rich in chalcopyrite, and is sometimes accompanied by the silver cobalt ores. The other group comprises tin deposits.

The first group comprises iron pyrite as its most abundant ore, with zinc-blende (especially the dark-colored variety), argentiferous galena and chalcopyrite, to a less extent arsenical pyrite, arsenopyrite and pyrrhotite; very rarely rich silver ores, such as polybasite, argentite, ruby silver, native silver. The second group includes cassiterite (often in long columnar crystals), molybdenite, hematite and arsenical pyrite.

The minerals characteristic of the pyritous-blende-deposits are almost everywhere present when the beds carry any ores at all, but the proportions of the minerals vary. As the predominant mineral may be blende, replaced deeper down by chalcopyrite or galenite, the deposits have been in the course of years worked for limonite, then as silver lead and afterwards as copper mines.

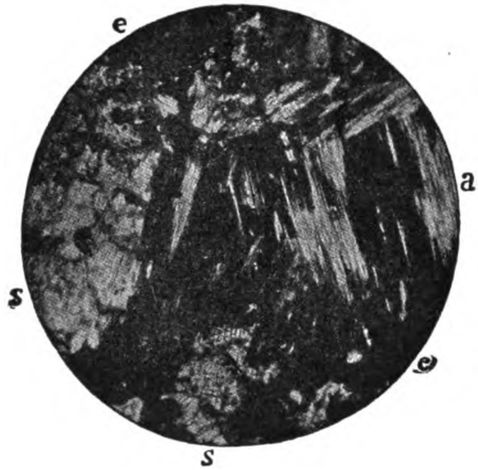


Fig. 191.—Thin section of an ore from the main bed of the Gelbe Birke mine, near Schwarzenberg.

S, salite (melacolite) in part transformed into *a*, actinolite; e, zinc-blende with chalcopyrite saturating a mat of actinolite fibers. (Enlarged 50 times.)

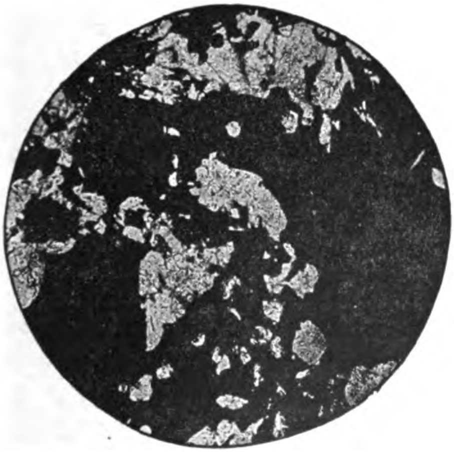


Fig. 192.—Thin section of an ore from the Fortuna mine near Breitenbrunn. Shows an aggregate of greenish yellow garnet partly replaced by arsenopyrite (black). (Enlarged 50 times.)

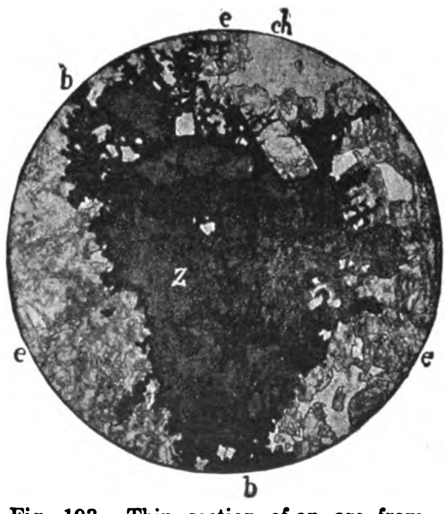


Fig. 193.—Thin section of an ore from Fünf Brüder Fundgrube at Antonsthal. e, epidote; ch, chlorite (peninite); z, yellowish brown zinc-blende; b, galenite. (Enlarged 50 times.)

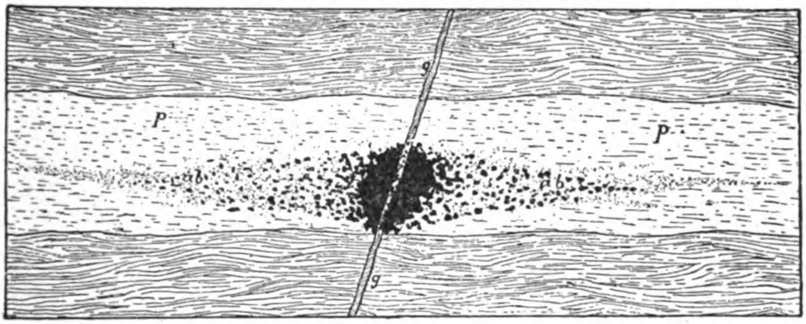
Where the greenstone sheets, as they will be called for brevity, are the richest in ore they are always found to be strongly altered. The salite is more or less altered into actinolite, each gradation being seen in thin sections, and this product of alteration has been saturated with silica, producing prase and flint, and jaspery aggregates. In other cases epidote and a chlorite (mostly penninite) have been formed, or even the entire bed has been transformed into talcose and serpentinous aggregates. The metallic sulphides occur either in fine interspersed grains, in small stringers or pockets, or they form compact continuous bodies. The microscope shows that these ores and the quartz, wherever they occur with the silicates, are always the ingredients last segregated. The sulphides fill the interspaces between the metamorphic silicates, epidote (pistazite), actinolite and chlorite, but have also penetrated along fissures and cracks into the grains and crystals of garnet and salite, and quartz has also often been deposited similarly with them. The views of thin sections, Fig. 191 to 193, with their explanations, will elucidate what we have just said.

The ore is not uniformly distributed through the bed, but is often concentrated in pay streaks in the greenstone, the rest of the greenstone being almost barren. These streaks show an evident close connection with fissures cutting through the rock; indeed, these fissures also contain pyritous blendic lead ores, and in some cases also rich silver-cobalt ores, though never in workable amounts. Hence the mining work was not a simple extraction of a bed, for the workings followed the fissures in order to find the ore streaks. Thus, according to H. Müller's notes, in the Unverhofft Glück, a greenstone bed has been developed for 600 m. (1,968 ft.) in length and 120 m. (393 ft.) in depth, the workings following a vein 2 to 4 meters (6.5 to 13 ft.) or rarely 8 meters (26.2 ft.) thick, and dipping 45 to 55° west. In this mine the workable ores were all confined to the proximity of the transverse fissures, a great number of which were encountered in the field. The great orebody at Catarina shaft, for example, followed the intersection of the bed with the Hoffnung-Morgengang. The second nearest to the Hahnschacht lay at the intersection with a 'stehende' vein. In the Gelbe Birke and Hercules Frisch Glück mines, an ore bed, for the most part worked only for zinc-blende, contains a rich orebody 16 meters long and 40 centimeters thick, which has recently been followed, according to F. J. Fröbe, along the line of intersection of a narrow cross vein that is a few centimeters thick. This rich orebody consists mainly of chalcopyrite, with some blende and galenite. At the same time an extensive body of arsenical pyrite is exposed in the main ore bed of the Sanct Christoph mine, near Breitenbrunn. This plainly shows how the pyrite impregnation of the greenstone stratum depends on the vein traversing it, a vein which also carries arsenical pyrite, as represented in Fig. 194.

A similar impregnation of wall rock with arsenopyrite from a vein may be observed in the Neue Silber-Hoffnung mine on the lower of the two magnetite deposits.

The cassiterite and the accompanying minerals of the tin formation, including, besides the above named ores, fluorite, chlorite, tourmaline and apatite, as gangues, does not occur in all the Schwarzenberg beds. Cassiterite occurs mainly in the mines at Breitenbrunn, where the Fortuna, Kaltwasser, Alte Grube and Sanct Christoph had been producing magnetite and cassiterite during the 16th and into the 17th centuries. In the 18th century more and more pyrite was found with increasing depth, and since 1781 pyrite alone has been produced, with very little tin ore. From the

sch



sch

Fig. 194.—Longitudinal section of the main ore bed of the Sanct Christoph mine near Breitenbrunn.

sch, gneiss-mica-schist of the hanging-wall and foot-wall; p, pyroxene-actinolite rock, in the lower part, with layers of magnetite; g, Osterfest Spat lode; ab, impregnation with arsenopyrite, zincblende and some chalcopyrite, richest immediately next to the lode. (Length of the profile, 80 meters.)

old Sanct Christoph Zwitterbaue 100 to 200 quintals of tin were taken in some years. At Breitenbrunn both the hanging-wall and the bed itself were found to be traversed by stringers of tin ore, which also contained silver cobalt ore, probably in a secondary band or layer, as observed in many lodes of Johanngeorgenstadt.

There can hardly be a doubt that the minerals of the tin formation found in the Schwarzenberg beds also owe their existence to an impregnation from veins. H. Müller and Freiherr von Beust long ago recognized both the sulphides and the tin ores of the Schwarzenberg beds as later impregnations in the salite actinolite beds[1]. This was adopted by K. Dalmer, who,

[1] See theory that vapors and solutions, as an aftermath of intrusion, penetrate actinolitic and garnetiferous beds because of their porosity. 'Ore Deposits near Igneous Contacts.' W. H. Weed: *Trans.* Am. Inst. Min. Eng., October, 1902.

however, refers the phenomenon to the contact metamorphism so generally prevalent in that locality, while F. Schlach, without regard to structure or the distribution of the ores, decided in favor of a syngenetic view.

Mining in the Schwarzenberg district is now of slight commercial importance. In 1898 1,345 tons of magnetite, and small quantities of chalcopyrite, zinc-blende and arsenopyrite, were produced. Since then there has been a further decline. The Saxon Erzgebirge contains quite a number of deposits, analogous to those of Schwarzenberg, not only in the mica schist, but also in the gneiss and phyllite areas. Those that contain magnetite, pyrites and also cassiterite will be noted first.

Near the Geyer granite mass the mica schist contains the Hochmuth and Neues Glück ore bed, carrying magnetite, pyrite, blende, galena and tin ore; at Thum the phyllite contains the Silberzeche bed, carrying axinite.

At Kaffberg, near Goldne Höhe, northwest of Gottesgabe, the Breitenbrunn conditions are almost exactly repeated, with the difference that in the former place the ore-bearing greenstone strata are intercalated in the phyllite gneisses of the phyllite formation[1]. Similar occurrences are found at Johanngeorgenstadt.

Other deposits consist merely of magnetite and pyrite, blende and galenite, as, for example, the orebodies worked until 1807, mainly for copper ore, in the mica schist at Kupferhübel, near Kupferberg, in the Bohemian part of the Erzgebirge[2], and other numerous occurrences of that region, one of which has quite recently been reopened near Pressnitz for the extraction of magnetite. These deposits are found in various horizons of the crystalline schists, when the peculiar bed suitable for mineralization is present and fissures occur to serve as conduits. Granite intrusions are mostly though not always present in the vicinity, but it is quite possible, though not perfectly proven, that all these phenomena belong to contact metamorphism in the widest sense, as affirmed by K. Dalmer.

2. *The Orebodies in the Crystalline Schists of the Riesengebirge.*

On the south side of the Riesengebirge, the crystalline schists contain ore-bearing intercalations analagous to those of Schwarzenberg; thus, for example, according to H. von Festenberg-Packisch[3], in the fifties of the last century a bed of diopside rock approximating 2 m. thick was worked at

[1] K. Sternberger: *Zeitschrift* d. montan. Vereins im Erzgebites Joachimsthal, 1856. Nos. 10 and 11. Joh. Jokély: 'Zur Kenntniss der geol. Beschaffenh. des Egerer Kreises.' *Jahrb.* d. k. k. geol. Richsanst., 1857, p. 61 *et seq.* A. Sauer: 'Erl. zu Section Wiesenthal,' p. 43.

[2] A. Sauer: Erl. zu Section Kupferberg, 1882, p. 38

[3] H. v. Festenberg-Packisch: 'Der metall. Bergbau Niederschlesiens.' Vienna. 1881, p. 4.

Ober-Rochlitz. This contained large and small pockets of argentiferous blende, chalcopyrite, bornite, galenite and tetrahedrite. According to various older writings, summarized by B. von Cotta[1], a deposit formerly exposed from Ober-Rochlitz to Starkenbach is of special interest. Ore-bearing beds of diopside of great thickness occur there between mica schists and a crystalline limestone. The ores are mostly altered into secondary products. Reuss long since expressed the opinion that the ore impregnation was due to a quartz vein traversing the diopside[2] stratum and itself containing copper ores. At Spindelmuhl intercalations of hornblende schist carry arsenopyrite, iron pyrite, chalcopyrite, pyrrhotite and magnetite. In the Riesengrund, near the Schneekoppe, arsenopyrite and pyrrhotite occur in a layer up to two meters thick, and bodies of chalcopyrite are also known under a bed of limestone and garnet rock. At the Schatzlarloch, near Kleinaupa, the same ores are found, together with magnetite in a chloritic schist, crystalline limestone and a garnet diopside rock.

We may also provisionally include in this section the arsenopyrite and pyrite deposit of Reichenstein[3], although its genesis does not as yet appear quite clearly made out. At Reichenstein, near Glatz, in Prussian Silesia, the mica schists contain intercalations of crystalline limestone and of an augite-feldspar rock, the latter having undergone a profound alteration into serpentine masses (common and noble serpentines), tremolite and chlorite schists. At the largest of the mines, Reicher Trost, a thick serpentine mass has been exposed in contact with a limestone bed, the serpentine being connected with pyroxene feldspar rock, which has not yet been completely transformed. The bed has a maximum thickness of 40 m. (131 ft.) and has been traced to a distance of several hundred meters. The serpentine is the carrier of arsenopyrite, which, together with some magnetite, occurs disseminated through the rock, and also forms larger compact ore-bodies. The adjoining limestone, too, is traversed by veinlets of this ore-bearing dark-colored serpentine. The arsenopyrite is auriferous, so that originally only gold ores were mined, but, since the beginning of the last century, arsenic has been the chief product. The roasted arsenopyrite contains on an average 40 grams ($26.64) of gold per ton. Besides the above named ores, blende and galenite, carrying a silver and gold content, occur, as well as pyrrhotite, some chalcopyrite, bornite, pyrite and erythrite. Documents of as early a date as 1344 show that Reichenstein was a gold mining town. In 1900 the mines produced 3,530 tons of dressed arsenic ore.

[1] B. v. Cotta: 'Erzlagstätten,' II, p. 215.
[2] A lime-magnesia-pyroxene.
[3] R. B. Hare: 'Die Serpentin-Masse von Reichenstein,' etc. Breslau, 1879. F. Posepny: 'Goldvorkommen Böhmens.' *Arch. f. Prak. Geol.*, 1895, Vol. II, pp. 322–331. With bibliography.

There is a positively surprising resemblance of both mineralogic and geologic features between the Schwarzenberg (especially the Breitenbrunn) deposits on the one hand and those of Pitkäranta on the other.

3. *The Ore Deposits of Pitkäranta in Finland.*

Pitkäranta lies in the southeast part of Finland, on the northeast side of island-dotted Lake Ladoga. The outermost island has on it the famous monastery of Walamo. The mines are situated on the mainland close to the lake, in a gently undulating region abounding in rocky outcrops, or covered with marsh and scrubby forest. Farther away lie the mines of Huoponvaara at the northeast, Lupikko at the east and Heponselkä at the southeast, all belonging to the same group.

Up to the present time the best account of these deposits is the little monograph by Törnebohm[1]. A more extensive account is being prepared by Trüstedt.

The basal or bed rock in this region is a reddish granite gneiss, forming three dome-shaped masses. In the syncline between these three arches of gneiss is a series of conformable and younger crystalline schists, the lowest layer being a hornblende schist containing the orebodies, the uppermost layers being biotite gneisses and garnetiferous mica schists.

Recent mining developments show a difference[2] between a lower and an upper band of ore, each running perfectly parallel to and along the boundary of the granite gneiss.

The lower band consists mainly of a salite-garnet rock (locally called skarn), within which copper ores form subordinate masses. On the other hand, the ore band lying about 300 meters (984 ft.) above consists mainly of dolomitic limestones, containing pockets and layers of magnetite.

The younger crystalline schists are cut by numerous intrusions of granite rocks. The schists are cut off at Lake Nietjärvi and at Huoponvaara by the great Rappakivi granite mass. Moreover, pegmatites form veins and huge stocks, mainly in the lower ore band. The lower or main ore band has been opened since 1840 by a great number of small shafts. In the eastern mines it has a thickness of 3 to 4 meters, but increases gradually westward up to 20 meters (65.6 ft.), which, however, includes an intervening bed of hornblende gneiss. At the east it dips southward at an angle of but 20 to 30°, at the west at 60 to 70°. Immediately underlying it at the east is the granite gneiss; at the west a hornblende gneiss. Horn-

[1] A. E. Törnebohm: 'Pitkäranta malmfält.' *Geol. Fören. Förh.*, No. 137, Vol. XIII, part 4.

[2] From a brief communication kindly sent by Ingenieur Trüstedt.

blende gneiss immediately overlies it everywhere. The bed is not continuous downward, splitting up as shown in the deepest mine, the Omeljanoff IV shaft, in which at a depth of 100 meters it divides into several beds, that quickly wedge out, and between which there are pegmatitic masses intruded from below.

Its special composition is as follows: The true rock matrix, skarn, consists mainly of salite and garnet, the latter mineral predominating in the middle zone. This skarn is coarser-grained near the elongated and stretched druses which lie parallel to the schistosity and are filled with calcite, fluorite, quartz, garnet and various ores. The garnet often occurs in perfect crystals zonally built, and optically anomalous crystals of very diverse coloring. The ores consist of chalcopyrite, magnetite, cassiterite, to a less extent of zinc-blende, iron pyrite, more rarely yet of galenite, chalcocite, bornite and pyrrhotite. Occasional patches or grains of scheelite, molybdenite, native bismuth and bismuth telluride occur, and also secondary native copper.

Of all these ore minerals magnetite alone appears in the lower band under such conditions that it may be regarded as a primary constituent of the bed. It forms fine grained layers and lenses a few centimeters to several meters in thickness, sometimes enclosing druses with crystals of the ore, and with chlorite, calcite, xylotile and diopside. But when in the upper band we see the magnetite in distinct small veinlets[1] and stringers traversing the dolomitic limestone and the silicate rock, as was observed by Trüstedt in the limestone quarries Clara I, and the Herbert shaft, one doubts the primary nature even of this constituent.

The chalcopyrite in the lower band shows a decided preference for the diopside 'skarn,' where it fills the interspaces between the grains of salite, usually altered to chlorite and actinolite. The same is true of the blende and the other sulphides. The cassiterite was mainly concentrated in the tin mine (Omeljanoff II, III). It occurs in fine disseminated particles and in lumps, and not only in the skarn, but also alongside of it in the pegmatite, a feature that is also true of the chalcopyrite and the molybdenite. The cassiterite-bearing veinlets of the decomposed pegmatite cut through the feldspar intergrowths. The well-known needle tin (Nadelzinn) crystals occurs with calcite and quartz in druses in the skarn. Törnebohm regards the entire series of crystalline schists of the region as a metamorphic formation. According to him the skarn originated from beds of impure ferruginous limestone. Subsequently the cassiterite and its accompaniments, such as fluorite, scheelite and molybdenite, were introduced

[1] A. Lacroix: 'Melanite Carrying Veins of Magnetite,' *Guide*, Congrès Int. Geol., 1900, p. 12.

by pneumatolysis, and lastly chalcopyrite, iron pyrite, and the other sulphides. He lays stress upon the fact that tin crystals are found completely enclosed by iron pyrite and chalcopyrite, never the reverse. All these mineralizations took place as a sequel to the intrusion of the pegmatites, and perhaps also of the Rappakivi granite.

4. *Kallmora Silver Mine at Norberg, in Sweden*[1].

This seems the proper place in which to mention a peculiar ore deposit found at Kallmora Silfvergrufva, in the Norberg iron ore district, described previously.

The country rock is a fine-grained, well foliated biotite gneiss. In the beds immediately above and below the ore, the rock is either poor in feldspar or devoid of it, but contains in its place a light-colored pyroxene, some hornblende, garnet and cordierite. The structure is exceedingly suggestive of the mosaic structure of the contact metamorphic rocks about granitic intrusions. The cordierite, too, is encrusted with quartz granules in the same way as in the true contact metamorphic hornfels. A good deal of magnetite occurs in layers in this country rock. There is no doubt it is a primary constituent, for it often forms sharp crystals alongside of the quartz veins, and is often penetrated from all sides by quartz individuals. The case is quite different with the galenite, which is also found sometimes interspersed in the gneiss. This is a later immigrant filling the gaps between decomposed pyroxene grains. The bed, which is 3 to 5 m. (9.8 ft. to 16.4 ft.) thick, and dips almost vertically, is mainly a crystalline limestone, grading irregularly into a garnet pyroxene skarn rich in fluorite. In its upper part the skarn becomes subordinate, and the ores were found directly in the gneiss (the so-called granulite). The oxidic and sulphidic ores remain, on the whole, rather sharply separated, as shown by the cross-sections prepared by the owners. The oxide ores consist of magnetite and hematite, forming streaks and layers in both the upper and lower bands of gneiss, especially where it contains garnet and pyroxene, that is to say, where it becomes skarn-like. The sulphide ores form extensive bodies of galenite, with 0.015% silver (in sample at Freiberg) and smaller bodies of pyrite, chalcopyrite and arsenopyrite, and occur as isolated masses in the midst of limestone and skarn, or occasionally, as for example at the depth of 100 m. (328 ft.), replace the bed for its entire thickness. The fine crystalline galena predominates, but is accompanied by colorless or violet fluorite, calcite, and some garnet. A coarsely foliated variety of this ore also

[1] G. Nordenström: Mineralogiska notiser in *Geol. Fören. Förh.*, Vol. IV, No. 12, p. 340. A. Helland: 'Bergbeg, Anthracit og nogle andre kulholdige Mineralier fra Ertsleiesteder og Granitgange.' *Geol. Fören. Förh.*, 1874–75, p. 513. R. Beck: 'Ueber einige mittelschwedische Eisenerzlagerstätten.' *Zeit. f. Prak. Geol.*, 1899, p. 1.

occurs, forming stringers penetrating coarsely crystalline segregations of quartz in the garnet skarn. A later introduction of the precious metals is indicated by the occasional occurrence of distinct crusts. Thus blunt crystals of 'greasy' quartz occur in the garnet skarn, surrounded by a thin layer of chalcopyrite, and often penetrated by small stringers of this mineral. On one side of one of these quartz segregations, there is a large patch of coarsely crystalline galenite. In rare cases the ore contains secretions of calcite, with fluorite and chlorite, enclosing débris of clearly identifiable magnetite, in part as fine as dust. This shows that the primary magnetite layers were crushed before the introduction of the calcium carbonate and calcium fluorite, which cemented the powder. Equally important genetically is the presence of garnet fragments in the fluorite and sulphide ore mixture, garnet fragments being sometimes surrounded by coarse, foliated galenite, and being furthermore traversed by fine stringers of the ore. G. Nordenström also describes from Kallmora sessile crystals of magnetite, which thus would seem to occur here also as a new secondary formation.

In the upper part of the deposit the galenite ores are somewhat oxidized and friable, and hold stringers and bunches of calcite, with asphalt-like anthracite up to 500 c. c. The granules and lumps of anthracite are seen to be not only enclosed in the calcite, but are also penetrated by a network of calcite veinlets. This remarkable association is not unique, for asphalt-like masses also occur in iron ore at Moosgrufva and Kilgrufva.

From these observations it is seen that at Kallmora the magnetite and garnet seem to be older constituents, while galenite, chalcopyrite, arsenopyrite, fluorite, calcite and asphalt immigrated later, after faulting. The former is indigenous to the country rock in its present metamorphic condition, the latter guests in it.

The total output of lead ore from the Norberg mines from 1891 to 1895 was on an average 6,661 tons per year. The ores formerly smelted at Freiberg now go to Sala. Until a few years ago they were sent to the Freiberg furnaces.

5. *The Deposit of Schneeberg, near Sterzing.*

The Schwarzenberg and Pitkäranta deposits are closely related in character to a number of deposits in the Austrian Alps, particularly that of Schneeberg, near Sterzing, although the latter in turn presents many analogies with the deposits of Bodenmais and Broken Hill. An account of the Alpine deposits is introduced here, because the ores consist of sulphides together with magnetite.

The rocks about Schneeberg, south of Innesbruck in Tyrol[1], consist of mica schists, with garnet, staurolite, cordierite, feldspar and gneiss. In addition there are thin intercalations of amphibolites, calcite-muscovite schists, calcite-biotite schist, quartzite and dolomite.

The deposit is intercalated in the mica schists and varies greatly in thickness, its average being 4.26 feet (1.3 m.). Its length is 800 m., and it has been mined for 300 m. in depth. The ore consists of zinc-blende and argentiferous galenite, which, according to von Beust's estimate, exist in the proportions of 10 to 1, in a gangue of quartz and breunnerite. The accessory minerals comprise pyrrhotite, pyrite, arsenopyrite, chalcopyrite, boulangerite, argentite, tetrahedrite, native silver, as well as magnetite, menaccanite and limonite; with the following gangue minerals: calcite, dolomite, fluorite, apatite, garnet, actinolite, chlorite, biotite, muscovite, and finally, decomposition products of the ores.

The Schneeberg deposit was regarded by von Beust as a bedded vein; by Posepny as a metasomatic formation due to the replacement of an anhydrite bed; by von Elterlein as a lode.

That it is a bed of the character of the Schwarzenberg deposit, is borne out by the mineralogic composition. The following facts enumerated by von Elterlein favor the vein theory: (1) The symmetry, which is often pronounced in the succession of the various layers composing the deposit. (2) The fact that the stratification of the country rock is occasionally cut through. (3) The presence of a quartz stringer, and (4) the occurrence of cockade ores, that is to say, fragments of the country rock encrusted by layers of ore. Conceived as a lode, the deposit would belong to a variety of the pyritous-blende lead deposits, characterized by special gangues.

The Schneeberg mining industry began in the sixties of the 15th century, and was directed at first to the silver in the galenite. After an interval of idleness, work was resumed in the seventies of the 19th century, and the deposit is now worked solely for the rich zinc-blende ores, whose exploitation proved to be remunerative after the introduction of a magnetic method of dressing. The Schneeberg mine, at an elevation of 7,321 feet (2,232 m.) above the sea, is the highest mine in Europe since the close of the gold mine of the upper Rauris. Similar deposits described by Canaval[1] occur in Carinthia. Only a few of them can here be briefly mentioned.

[1] K. Frhr. v. Beust: 'Ueber die Erzlagerstätte vom Schneeberg,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1870, Vol. XX, part 4. *Idem:* 'Die Erzlagerst. vom Schneeberg,' etc. *Oesterr. Z.* f. B. u. H., 1871, p. 201. F. Posepny: 'Ueber die Lagerstätte am Schneeberg in Tirol.' *Oesterr. Z.* f. B. u. H., 1879, p. 106. A. v. Elterlein: 'Beiträge zur Kenntniss der Erzlagerstätte des Schneeberges,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1891, pp. 289–348.

[2] R. Canaval: 'Zur Kenntniss der Erzvorkommen des Lamnitz- und Wellathales in Kärnthen.' Carinthia, II, No. 5, 1898.

In the valleys of the Lamnits and the Wella, the prevailing crystalline schists contain pyrite beds 1 to 12 ft. (0.3 to 3.7 meters) thick, between a hornblende schist and an underlying garnet mica schist. The beds consist of pyrite mingled with quartz, pyrrhotite and chalcopyrite, zinc-blende, and some galenite. Uralite, tremolite, zoisite, biotite, fibrous hornblende, titanite, albite and calcite are also mentioned.

At the Kanappenstube, near Oberdrauburg, a deposit[1] is known which consists of pyrite, pyrrhotite and calcite, with subordinate arsenopyrite, galenite and zinc-blende in a gangue of quartz, albite, labradorite, muscovite, biotite, augite, epidote, zoisite, titanite, tremolite-like hornblende, rutile, ankerite, calcite and graphitic substances. The arsenopyrite contains 104 grains of gold per ton. A garnet-bearing pyrite bed also occurs at Lading[2].

6. *The Copper-bearing Sjangeli Schists.*

The remarkable copper ore deposits of Sjangeli, in Swedish Lapland, are placed provisionally in this class. They lie close to the Norwegian boundary, southeast of Torneå, and are as yet undeveloped. They consist of zoisite-bearing hornblende schists which carry bornite and chalcocite, together with some chalcopyrite, in the form of disseminated granules, streaks or small lenses, in part also in the form of stringers. These sulphidic ores are accompanied by magnetite. The geology of this region is described in a paper by W. Petersson[3].

(β) Epigenetic Deposits of Sulphidic Ores.

I. Zinc-blende Deposits.

1. *The Zinc-blende Deposits of Ammeberg, in Sweden.*

The zinc mines of Ammeberg[4] lie near the north end of Lake Vetter, in the Orebro district.

The steeply dipping beds of blende occur in a band of fine-grained, gray, biotite gneiss, with red fine-grained, biotite gneiss (Rödgranulit) on the

[1] R. Canaval: 'Zur Kenntniss der Erzvorkommen in der Umgebung von Irschen und Zwickenberg bei Oberdrauburg in Kärnthen.' *Jahrb.* d. naturh. Landesmus. f. Kärnthen, 1899, part 25.

[2] *Idem:* 'Ueber das Kiesvorkommen von Lading.' *Jahrb.* d. naturh. Mus. von Kärnthen, 1901, part 24.

[3] W. Petersson: 'Om de geologiska förh. i trakten omkring Sjangeli kopparmalmsfält i Norrbottens län.'

[4] B. Turley: 'Der Zinkbergbau der Altenberger Gesellschaft bei Ammeberg in Schweden.' *Berg u. Hütten. Zeit.*, 1866, p. 405 *et seq.* A. E. Törnebohm: 'Beskrivning till Bl. No. 7 af Geolog. Öfversigtskarta öfver Mellersta Sveriges Bergslag.' 1881, p. 31 *et seq.*

north and a coarse-grained biotite augengneiss[1] on the south. (See sketch-map, Fig. 195.) Minor bands of crystalline limestone occur in the steeply dipping gneisses, with two deposits of blende near by. Both these bands of zinc-blende conform to the abrupt folds and turns of the gneiss, both at Lake Trij and east and west of it. North of Lake Trij a stock of medium-grained granite traverses the schists, while in the eastern part of the field a mass of gabbro (gabbro diorite) insinuates itself more in the line of the strike. The northern deposit, with the Victoria and Lyck mines, is the least important. The other, the main deposit, is situated on the hanging side of the limestone, and has been opened in several shafts. This ore band can be traced continuously for 5 km. (3 m.), except where the granite massive at Lake Trij cuts through and interrupts it. It consists of lenticular bodies succeeding one another in a series, their thickness varying greatly, though in most cases it is 4 m. to 6 m. (13 ft. to 19.6 ft.), exceptionally 12 m. (39.3 ft.). The northern boundary plane (the hanging-wall of the mines) is against the gray, fine-grained gneiss, and is apt to be sharply developed, and the rock is readily detached from the ore. Close to the foot-wall, an intercalation of a handsomely stratified wollastonite rock, banded in cross fracture, sometimes appears.

In the open-cut close to Perier this intercalation is again succeeded by an ore bed about 40 meters thick, before the foot-wall is reached. The foot-wall is formed of a micaceous skarn, very rich in pyrrhotite, itself underlain by a light-colored, banded lime-silicate rock, consisting mainly of wollastonite, and enclosing layers of crystalline limestone. Next follows a fine-grained biotite gneiss, which in certain slightly micaceous layers closely resembles granulite. The ore bed itself also shows a peculiarly distinct bedded structure, the layers of ore alternating with barren or poor layers of wollastonite rock or fine-grained scaly gneiss (halleflinta). In certain cases some of the bands of the bed are greatly crinkled and twisted, while others close by show but feeble bends. The photograph of an ore specimen shown in Fig. 196 exhibits on a small scale the crinkling seen on a grand scale in the view at the top of the mines.

The deposit shows many pegmatitic masses intercalated in and alongside of the bed, mostly as bedded veins, sometimes as what appear to be entirely isolated lumps arranged more or less parallel to the stratification, but sometimes cutting across the bedding; thus between Vilain and Perier the ore bed is in one case completely cut off by a broad pegmatite mass. These pegmatites are rather coarse-grained and consist in the main of a microcline, colored green when exposed to the air, together with some quartz, and

[1] Augengneiss or porphyritic gneiss is one in which large eye-like kernels of orthoclase or quartz are dispersed through a finer matrix (Geikie, p. 321).

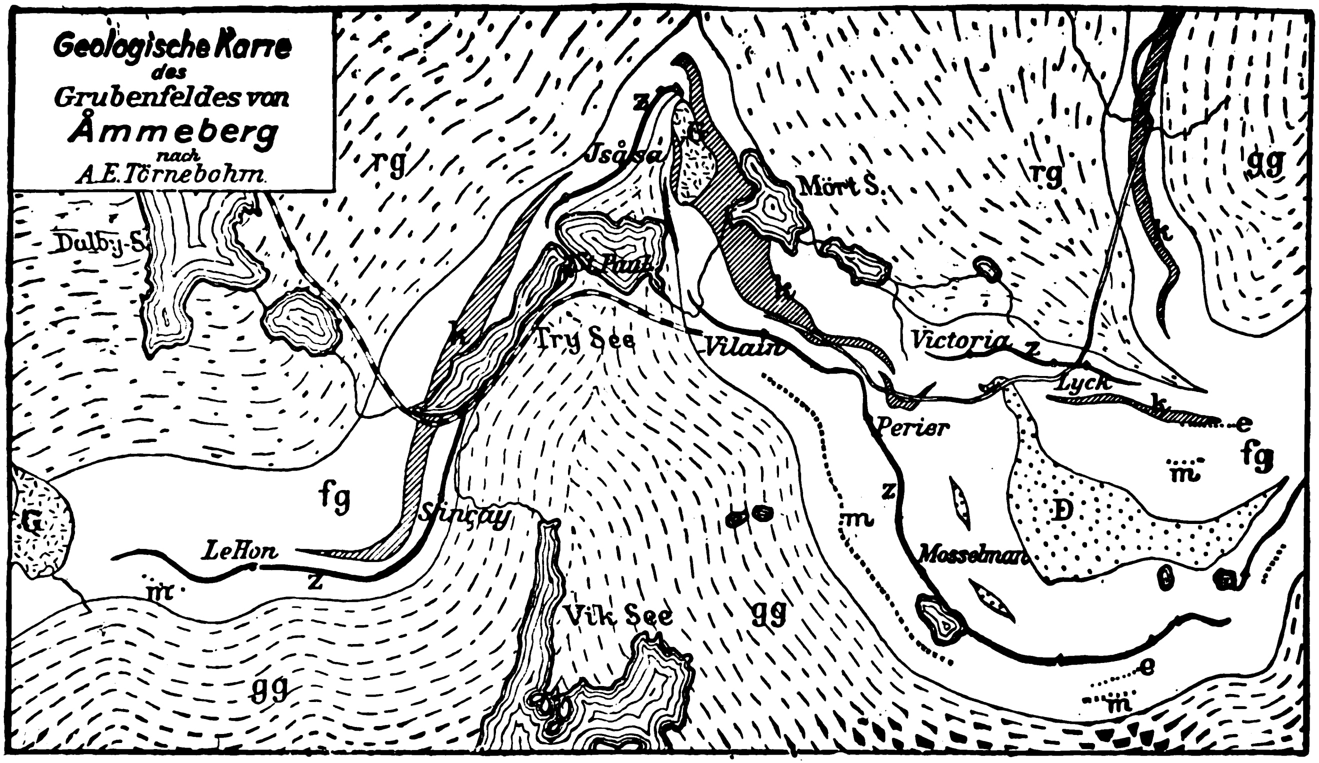


Fig. 195.—Geologic map of the Ammeberg mining district. (A. E. Tornebohm.)

Explanation of symbols: rg, fine-grained red gneiss; fg, fine-grained gray gneiss; gg, coarse-grained gray gneiss; k, limestone; e, eclogyte; G, granite; D, gabbro diorite; z, zinc-blende; m, pyrrhotite; ǒ, shaft.

sometimes they also contain black tourmaline. Furthermore, transverse veins of a fine-grained granite are distinctly observed in the country rock. These aplites and pegmatites are evidently connected genetically, since granite veins of this kind are found which show a transition to a coarse pegmatite in the center. Narrow calcite stringers, with small nests of asphalt, are occasionally found, and exhalations of inflammable hydrocarbons repeatedly took place on fissures. Very rarely minute cross fissures in the deposit contain sheets and rough nuggets of native silver.

The steep dip of the beds prevails in general to the lowest depths (down to 650 feet), save in the southernmost part of the field, where the dip lessens. For part of its course the main blende bed is accompanied by an

Fig. 196.—Strongly wrinkled portion of the blende layer with dark bands of gray gneiss. (One-half natural size.)

underlying perfectly parallel pyrrhotite layer, which is for the most part, it is true, merely a band of pyrite-impregnated gneiss. The mines have belonged to the Vieille Montaigne Company and have been vigorously worked since 1857. The ores are roasted at the mine, then shipped to Belgian zinc furnaces. From 1891 to 1895 there was produced an annual average of 23,-535 tons of ore.

2 *The Zinc-blende Deposit of Långfallsgrufva, near Räfvåla, Sweden.*

The Långfalls mine[1] lies south of Lake Vessman, west of Ludvika, in the province of Dalarne. It belongs to the Saxberget Mining Company.

The deposit is 3 to 5 meters thick, outcropping beneath a glacial cover, as shown in the accompanying section, Fig. 197. It is conformably intercalated in crystalline schists which dip steeply south. The prevailing rock

[1] R. Beck: 'Ueber die Gesteine der Zinkblendelagerstätte Langfallsgrube,' Tschermak's *Min. u. petr. Mitth.*, Vol. XX, 1901, pp. 382–389.

is a fine-grained fissile biotite gneiss (granulite of the Swedish geologists), which is also found immediately underlying the deposit. In the hanging-wall, on the contrary, actinolitic rocks prevail, forming a band of about 40 meters (131 ft.) thick, in part strongly impregnated with blende and other ores. The orebody proper consists mainly of zinc-blende, and to a less extent of pyrrhotite, chalcopyrite, iron pyrite and argentiferous galenite. The distribution of these ingredients is not uniform, the galenite and pyrrhotite being accumulated in patches. At certain points the chalcopyrite is the most abundant ore. The ores merely form a more or less prominent filling amid bunches and individual needles of greenish gray monoclinic anthophyllite, which are evidently strongly corroded. Furthermore, the mixtures of ores contain grains of etched and corroded, partly decom-

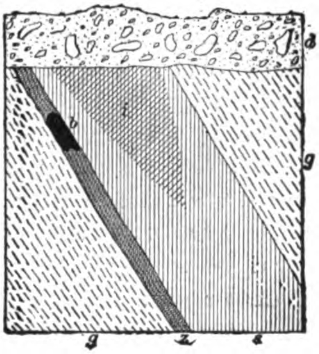


Fig. 197.—Section through the ore deposit of Langfallsgrufva near Råfvala.
s, actinolite rock which, at i, is impregnated with zinc-blende; z, zinc-blende deposit proper; b, orebody rich in galenite and pyrrhotite in the blende deposit; g, fine grained biotite gneiss, d, drift.

posed, polysynthetically twinned cordierite with cracks filled by ore, also grains of green translucent spinel, and some of a red-brown staurolite. Not infrequently the ore is found to contain coarse-grained, crystalline, pocket-shaped or lenticular segregations. These consist of quartz, orthoclase, plagioclase and cordierite of a blue or greenish variety, and green, translucent spinel, which encloses ore particles arranged in rows. The gray actinolitic rocks contain intercalated layers formed of a common green actinolite-hornblende. Pegmatites containing a green orthoclase also have been found in the midst of an orebody.

The mine was found in 1881 or 1882, the deposit having been located, despite its cover of forest, by magnetometric methods, and notwithstanding its comparatively small content of pyrrhotite. The production in the year 1897 was 600 tons of picked zinc-lead ore (stufferze);

11,000 tons of dressed ore and 109 tons of picked copper ore, while the mixture of actinolite impregnated with pyrrhotite and iron pyrite, and constituting about 4,000 tons of the output, is not put to any use.

In view of the great similarity in mineralogic composition, the description of the Långfallsgrufva deposit may be very appropriately followed by that of the long known occurrence of Bodenmais, although this is not a true zinc deposit, and hence does not really belong under the present heading.

II. The Pyrrhotite and Pyrite Deposits of the Silberberg at Bodenmais[1].

These deposits lie in a zone of biotite gneiss, distinguished by a great wealth of accessory minerals, such as garnet, cordierite, sillimanite, rhombic and monoclinic pyroxenes, zinc, spinel and menaccanite. E. Weinschenk regards these gneisses as contact metamorphic rocks, which owe their gneissoid condition to the intrusion of the granite mass near by and an injection with granitic magma. A similar view had previously been expressed by J. Lehmann. The rock is strongly folded, and in those parts that are particularly compressed it contains many irregular quartz aggregates, most of them lenticular. Orebodies occur only a few meters from the contact, the larger and richer ones being found at a greater distance. Toward the middle of the gneiss zone, which abuts against granite, the ores disappear entirely, according to the author last named.

The orebodies have the form of very irregular lenses, which often send branches into the country rock. In the upper bed their diameter not infrequently reaches 8 m. (26 ft.), with a length of 10 m. to 20 m. (33 ft. to 66 ft.) along the strike; sometimes, as in the great Barbara cut, the thickness reaches 16 m. (52 ft.) The deposits, as a rule, are found where the country rock is most disintegrated and is especially rich in quartz lenses. For that matter, they also occur toward the west, at horizons so diverse that the older division of the orebodies into three bands no longer appears justified.

The orebodies consist mainly of non-nickeliferous pyrrhotite, pyrite, chalcopyrite and zinc-blende. Some argentiferous galenite occurs, confined

[1] W. v. Gümbel: 'Geogn. Beschr. des Ostbayerischen Grenzgebirges,' 1868, pp. 548, 552. J. Lehmann: 'Entstehung der Altkrystallinen Schiefergesteine,' etc. Bonn, 1884. pp. 175–178. E. Weinschenk: 'Die Erzlagerstätten am Silberberg bei B.' *Glückauf*, 1898, No. 45, pp. 4–9. P. Wagner: 'Die Kieslagerstätten von Bodenmais.' *Naturw. Wochenschr.*, 1898, Vol. XIII, No. 25. E. Weinschenk: 'Der Silberberg bei Bodenmais.' *Zeit. f. Prak. Geol.*, 1900, pp. 65–71. *Idem*: 'Die Kieslagerstätte im Silberberg bei Bodenmais.' *Abh.* d. k. bayer. Ak. d.W., 2d ser., 1901, Vol. XXI, part II, pp. 349–410. K. Gruber: 'Der Schwefel- und Magnetkiesbergbau am Silberberge bei Bodenmais,' pp. 339–348.

to a very restricted area, and some cassiterite is present. The pyrrhotite and pyrite always predominate, but the amount of each mineral varies widely from place to place. The ore is compact, vugs being very rare. Minerals of secondary formation are found in sessile crystals, including zeolites, spessartite (manganese-alumina-garnet), vivianite, gypsum, barite, etc. There is no real gangue, but the mixture of minerals includes rounded, apparently etched grains of quartz which in many cases show secondary enlargement, also grains of cordierite, feldspar, andalusite, zinc-spinel, rhombic pyroxene and other constituents of the surrounding gneiss. These grains contain a core corresponding in composition to that of the same mineral when in the gneiss, but the accretions about the core contain, according to E. Weinschenk, numerous inclusions of pyrrhotite. The orebody sometimes shows symmetrically banded mineral crusts. The country rock next to the selvage is often rich in coarse-grained, gray-green feldspar. The ore deposit begins with a thin layer of galenite; next to it is a layer of zinc-blende, then one of pyrrhotite, and finally the central band or core of mixed sulphides. Toward the west the deposit holds occasional fragments of the country rock, surrounded by successive crusts in the order just named, forming cockade ores. Patches of country rock impregnated with ore, which are often found near the orebodies, exhibit a micro-breccia structure (cataclasis). The sulphides and the zinc-spinel have been deposited in the microscopic fissures and cracks of this rock. In such cases the chalcopyrite seems to be the last mineral to be formed.

The masses of vesicular, slaglike ore described by E. Weinschenk may be due to the secondary leaching out of some constituent, as has been observed in other deposits. Different observers have held very different theories of the genesis of the pyrite deposits of Bodenmais. The older authors as a rule believe the ores to have been formed with and as part of the country rock. The observations just mentioned show this view to be untenable. J. Lehmann thought that the ores were deposited in the cavities formed by the folding of the strata after the manner of the Australian saddle lodes. The invasion of the mineralizing solutions is supposed to be a direct consequence of the granite intrusion. E. Weinschenk, whose very minute investigations demonstrated the secondary introduction of the ores, is alone in his belief that the ores are due not to solutions, but to an intrusive molten material resulting from the granite intrusion. Such a theory is opposed to all observed facts concerning granite intrusions and the contact phenomena connected with them. A true melting of the country rock (in the metallurgic sense) did not occur at all, as proved by the lack of glass inclusions, etc. Moreover, deep-seated plutonic intrusions are not apt to show a slag-like structure, such as he finds in the ore.

To us it seems that the facts show a genesis entirely analogous to that given for Broken Hill (see next paragraph), namely, the introduction of ore-forming solutions into zones of mechanically loosened rock, and a partial metasomatic replacement of the rock by the ore minerals, with enlargement and regeneration of a part of the corroded or entirely dissolved original constituents. It also seems probable that these phenomena are genetically connected with the intrusion of the granite. As a matter of history, it may be mentioned that at Bodenmais mining was originally directed only toward the higher grade ores of the gossan, beginning as early as 1364. In 1463 pyrite was first mined from the Barbara and Gottesgabe mines, mainly for the manufacture of vitriol. The average annual production of the Silberberg deposit in recent years is 20 metric quintals. The ores are at present used for the manufacture of green vitriol and fine rouge.

III. Silver-Lead Deposits.

The Ore Deposits of Broken Hill, New South Wales[1].

Broken Hill lies in the Barrier Range, which rises from the Tertiary plain north of the lower Murray river, and has a north-south course.

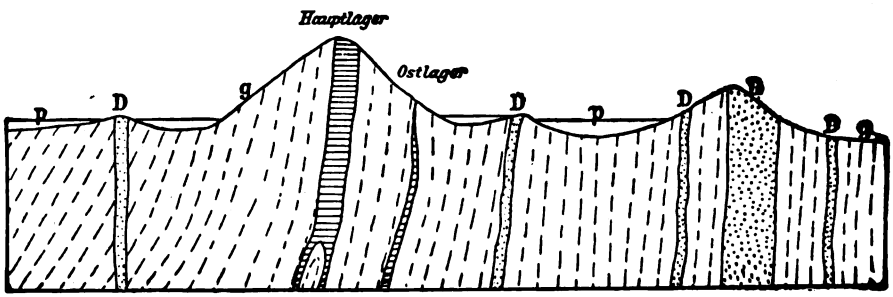


Fig. 198.—Section through the southern part of the Broken Hill deposit. (Jaquet.) g, gneisses, quartzites, and other crystalline schists; D, diorite; p, Pleistocene cover. (Hauptlager, main orebody; Ostlager, eastern ore-bed.)

This mountain area is of moderate elevation and is composed of crystalline schists, of undetermined age, intruded by masses of granite. The region is exceedingly arid and almost treeless, save in those valleys which occasionally carry water. Gneisses, quartzites and garnet rocks occur in steeply dipping strata in the immediate vicinity of Broken Hill and are traversed by numerous veins and stocks of dioritic rock, as shown in the section, Fig. 198.

[1] Jaquet: 'Geology of the Broken Hill Lode and Barrier Range Mineral Field.' *Mem.* Geol. Surv. of N. S. W., 1894. G. Eisfelder: 'Der Silber- Blei u. Zinkbergbau von Broken Hill,' *Berg u. Hütten. Zeit.*, 1898, No. 48–51. R. Beck: 'Bertrage zin Kenntniss von Broken Hill,' *Zeit. f. Prak. Geol.*, 1899, pp. 65–71.

The main lode of Broken Hill averages 59 feet (18 m.), but is sometimes 98 feet (30 m.) thick; it appears in cross-section as a stratum-like body, dividing below into two branches intercalated parallel to the banding of the garnetiferous biotite gneiss which adjoins it on both sides. The lode has been followed in the strike for a distance of 1.4 miles (2.4 kilometers), its outcrop forming a long, narrow, rocky line of hills. The mine workings show the rocks between the two branches of the vein to consist of quartz-garnet schists. A second unimportant orebody, lying at some distance east of the main lode, is intercalated in the garnetiferous gneisses.

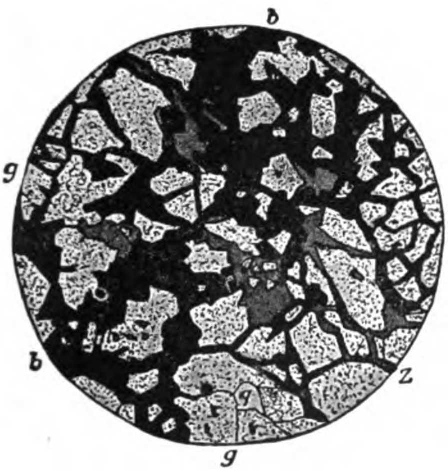


Fig. 199.—Micro-breccia of garnet rock with ores as cement. (Enlarged 50 times.) g, garnet; q, quartz; b, galenite; z, blende.

Fig. 200.—Garnet-rhodonite aggregate with immigrated ores. (Enlarged 50 times.) g, garnet; r, rhodonite; f, fluorite; b, galenite; z, blende; k, chalcopyrite.

The primary, unaltered ore of the Broken Hill lode is formed exclusively of argentiferous galenite and zinc-blende, in a gangue of quartz of a peculiar gray-blue tint, mixed with garnet, rhodonite and fluorite. This ore is now almost the sole product of the mine. The colorless or whitish fluorite usually escapes observation, being rarely in grains visible to the naked eye, or in stringer-like aggregates up to 3 centimeters wide. Less frequently chalcopyrite, pyrite, arsenopyrite and calcite are found.

Garnet is a constant and characteristic feature of the deposit. It forms innumerable tiny crystals in the midst of the ore and rarely, in larger, well developed crystals, shows numerous inclusions of sphalerite and galenite. The garnet, however, also occurs in the deposit in fragments of garnet rock, broken up into a breccia, galenite and blende furnishing the cement between the fragments (Fig. 199), and lastly, as large fragments of garnet rock, sometimes surrounded by a fringe of secondary garnet. (See the figures by the author in the *Zeitschrift fur praktische Geologie.*) The rhodonite is not present in all parts of the deposit; it forms large reddish-brown aggregates, intergrown with garnet, or occurs in isolated, much corroded individuals, traversed by fine veinlets of blende and galenite, and imbedded in the midst of the sulphide ore (Fig. 200).

The contact rock between the orebody and the gneiss is remarkable. This is composed of a verdigris-colored orthoclase, a little plagioclase,

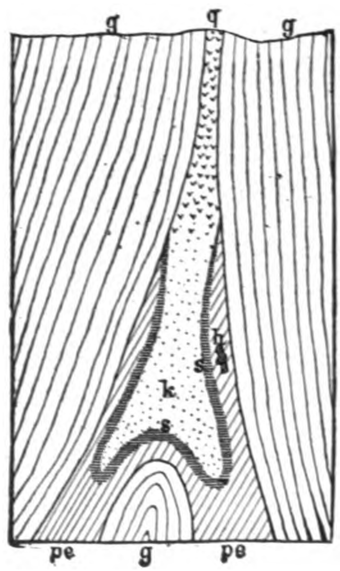


Fig. 201.—Ideal section showing the distribution of the ore in the upper part of the main lode of block 10. (Jaquet.)

g, garnetiferous biotite gneiss of the hanging-wall and foot-wall; pe, primary sulphidic ores; s, argentiferous secondary sulphidic ores; k, argentiferous kaolins; q, quartz and kaolin richly impregnated with oxides of iron and manganese.

scanty gray quartz, yellowish-red garnet, and dark mica. The wholly unstratified mass of the deposit shows, according to Jaquet, especially along the western boundary, protuberances which cut through the stratification of the gneiss. This feature may also be demonstrated on a small scale. Immediately adjoining the gneiss a specially garnetiferous zone with little ore nests is sometimes found, then a layer of quartz with comb structure, and finally the normal ore, enclosing great numbers of splintered quartz fragments.

The average content of the normal sulphide ore, according to Jaquet, is as follows:

Silver	0.15–11.19 kilograms per ton.
Lead	7 per cent to 50 per cent.
Zinc	14 " " 30 "

The gossan is of great economic and scientific significance, because of the presence of interesting secondary minerals and because it is exceedingly rich in silver (see section, Fig. 201).

The first alteration of the sulphide ores produces a cellular, honeycomb, spongy structure as a result of the leaching out of the silicates. In this way the leaching and removal of large rock fragments probably forms the drusy cavities occasionally met with in the orebody. These vugs are filled with fragments of quartz and garnet loosely cemented by argentiferous ore. Near the outcrop the metallic sulphides are more and more altered by decomposition, with an accompanying concentration of the silver at first into rich sulphidic silver ores, which are especially apt to impregnate garnet rock. In this usually narrow zone of secondary sulphide ores the amount of silver has occasionally been as high at 7.77 kilograms per ton. The explanation of this secondary formation of rich sulphides has already been given on page 378. Above these secondary ores is the great mass of gossan ore.

The deeper gossan ores consist of both very rich dry ores and lead carbonate ores. The former especially consist of kaolin completely impregnated with the chlorides, bromides and iodides of silver, together with native silver and decomposed garnet rocks, the whole carrying from 155 grams to 1.8 kilograms of silver per ton. The lead ore consists mainly of cerussite mingled with quartz and clay, impregnated with cerargyrite and native silver, as well as with manganiferous limonite, and usually containing 0.15 to 2.48 kilograms of silver per ton, and 20 to 60% of lead. Iodyrite, cerargyrite and embolite are often found in this part of the deposit in good crystals, also anglesite, stolzite, raspite, pyromorphite, smithsonite, fine specimens of native copper, malachite, azurite, cuprite, chrysocolla, and finally, in rare cases, the copper iodide called marshite.

Finally, the uppermost part of the deposit consists of ores formed of a mixture of limonite, psilomelane, quartz and clay, and containing many cavities, often giving it a slag-like appearance. In this also the rich secondary ores are found in individual crystals, especially in the druse cavities, from whose ceiling stalactites of psilomelane, limonite and calamine occasionally descend.

The genesis of the main Broken Hill lode is a very complicated problem. Pittman and Jaquet inferred from the structural conditions (inter-stratification) that the Broken Hill orebody is primarily the result of a great parting of the strata about an anticlinal fold of the gneiss. When a crescent shaped cavity was thus formed in the folded rocks, large slabs of country rock must have peeled off, and since a grating movement between hanging-wall and foot-wall must have taken place, at least on a small scale, these detached fragments might be further comminuted. The space partly filled with rock débris might then be occupied by the ores and the accompanying gangues, such as quartz, fluorite, and the newly formed constituent, garnet. Though this view, in a general way, seems to us at present the most probable, yet from the description given it may be inferred that extensive metasomatic replacement of the adjacent schistose rock alongside of the large cavities helped in the formation of this deposit. It is this which has led us to exclude the Broken Hill deposit from the class of mineral veins and to describe it in its present place.

The first silver deposits of the Barrier Range to be discovered (1882) were the true mineral veins of Umberumberka, which led to the founding of Silverton. In 1883 an unsuccessful attempt was made to prospect for tin ore on the Broken Hill lode; it was not until 1884 that the first rich cerargyrite ores were found. In 1886 the town of Broken Hill was founded, which by 1889 numbered 17,000 inhabitants, but suffered greatly at first from drought and vexatious labor strikes. Numerous companies are at work on the enormous deposit. From 1889 to 1896 inclusive the Broken Hill Proprietary Company, the most important of the corporations, distributed $30,000,000 dividends, and produced 290,000 tons of lead, besides 2¼ million kilograms of silver. The entire district produced 70,000 tons of ore per month. The annual production of lead was 168,000 tons, or 27% of the production of the globe.

Besides the Broken Hill lodes other similar deposits are found in the Barrier Range. Thus the Pinnacle[1] mines, 14 kilometers southwest of the town of Broken Hill, work orebodies intercalated in the garnetiferous gneiss in the form of strata without sharp boundaries. These ores, judging by the specimens, are a mixture of argentiferous galenite and pyrrhotite, with some zinc-blende, and very little stibnite, in a gangue of quartz, garnet and a little brown, fibrous hornblende, resembling dufrenite. The receptacle for the deposition of the ores here was apparently an actinolite garnet rock.

A noteworthy fact is that in the Broken Hill Consols mine, distinct veins are worked which intersect the schistosity of the crystalline rocks and which contain quartz and garnet, besides galenite, zinc-blende, rich silver ores, siderite and calcite.

[1] Jaquet, *Mem.* Geol. Survey, N. S. W., 1894, p. 108.

IV. Copper Deposits and Iron Pyrite Deposits.

1. *Copper Deposits of Schmöllnitz, Upper Hungary*[1].

Schmöllnitz lies in a deep lateral branch of the Göllnitz valley, cut in steeply dipping beds of slates and talcose, chloritic and micaceous schists. The ore deposits are confined to a zone of gray clay slate about 360 meters thick, intercalated in a series of blackish, carbonaceous slates. Two varieties of deposits occur, the first lenticular pyrite stocks; the second stratiform impregnations, called 'stripes' (Streichen). Three of these zones of slate carrying pyrite and chalcopyrite impregnations (the upper, middle and lower 'stripes') have been followed downward to considerable depths. The pyrite stocks, called the upper, or hanging-wall, the lower, or foot-wall, and the Engelbert stocks wedge out at a shallow depth. The largest orebody is the lower pyrite stock, which extends 420 m. (1,377 ft.) along the strike, and for 42 m. (465 ft.) on the dip, with a thickness of 42 m. (138 ft.) All the 'stocks' consist of banded iron pyrite with narrow layers of bornite and pockets of copper pyrite. Near the boundaries of the stocks the ore contains intercalations of slate. The deposits are traversed by several fault fissures, a fault in the lower pyrite stock showing a throw of 20 m. (65 ft.) Near the pyrite stocks, the 'stripes' also yield valuable ore. Silver-bearing lead and cobalt ores also occur in small amounts in the Schmöllnitz deposits.

2. *Bedded Copper Deposits of Graslitz, in Bohemia*[2].

The pyrite beds of Grunberg and Eibenberg, near Graslitz, in the western Erzgebirge, some ten in number, are intercalated conformably in the gently inclined quartz-phyllites which dip west, and have on the east been transformed into spotted schists and andalusite mica rocks by the action of the Eibenstock tourmaline granite. The strata, which are 1.3 m. thick, represent, as shown by the confused internal stratification, zones of gliding or slipping in the phyllite rock that have been subsequently mineralized. The quartz and silicified, chloritized, phyllite filling contain pyrite and copper pyrite as the main ore minerals; also arsenopyrite, magnetite, bornite, galena, siderite and zinc-blende. An admixture of tourmaline is of genetic interest; this may increase in amount until typical tourmaline rock is

[1] A. Hauch: 'Schmöllnitzen Hüttenprocesse,' *Oesterr. Z.* f. B. u. H., 1860, pp. 269–271. B. v. Cotta: *Berg u. Hütten Zeit.*, 1861, p. 151. G. Faller: 'Die Kupferbergbau in Schmöllnitz.' *Berg u. Hütten Jahrb.* d. k. k. Osterr. Bergak, 1867, pp. 193–197.

[2] B. von Cotta: *Berg u. Hütten Zeit.*, 1869, pp. 82, 83. C. Gabert: 'Die geol. Umgebung von Graslitz,' *Jahrb.* d. k. k. geol. R., 1899, 4. Also *Zeit. f. Prak. Geol.*, 1901, pp. 140–144.

developed with inclusions of calcopyrite. Accordingly it is possible that the ore impregnation is here to be regarded as a contact effect. At the present time an effort is being made to resume mining on the ore bed at this place.

3. *The Pyrite Deposits of Chessy and Sain-Bel*[1] (*Rhone*).

The once famous pyrite deposit of Chessy, northwest of Lyon, is now worked out. This deposit and the group of pyrite deposits of Sain-Bel lying 10 km. (6 miles) to the south, which are still actively worked, are in rocks of different age and character, and belong to the same north-south zone.

At Chessy the following section, based on the old data of Raby, revised by de Launay, is useful:

1. Cupriferous pyrite deposit enclosed by pre-Cambrian pyritized hornblendic schists (yellow ore).
2. Masses of black oxidized copper ore (black ore) and other oxidized copper ores (gray ore) in a zone of decomposed rock, which separates the schists just noted from the Rhaetic sandstone that adjoins them along a nearly vertical fault fissure.
3. Orebodies of cuprite and native copper in the red clay filling of the fault (red ore): from this ore the well known pseudomorphs of malachite after cuprite are derived.
4. Stringers, concretions and geodes of a finely crystalline azurite found in the Rhaetic sandstones and clays close to the fault and underlying lower Liassic limestone (blue ore).

The orebodies No. 2 and 4 are probably secondary products resulting from the destruction of older pyritic masses, such as No. 1.

The pyrite beds of Sain-Bel, east of the Brevenne, may be grouped into a northern and a southern field. Only the latter is worked at present, 320,000 tons of very pure pyrite being mined each year.

According to De Launay, the ore forms great lenses enclosed in hornblendic and chloritic schists. These lenses are grouped in a series or train 2 km. (1.2 miles) long. The great vein of the south field is one of the largest pyrite bodies of the entire world, being 600 m. (1,968 ft.) long, and 44 m. (144 ft.) in maximum thickness (at a depth of 166 m. or 544 ft.) This single lens has thus far yielded about 5,000,000 tons of ore. It consists of dense, unstratified pyrite, with a very slight amount of quartz. Other lenses, such as the western lens of St. Antoine, sometimes also contain chalcopyrite and zinc-blende. The copper ore is highly siliceous and

[1] L. DeLaunay: 'Die Schwefelkieslagerstätte von Sain-Bel,' *Zeit. f. Prak. Geol.*, 1901, pp. 161–170. Consult also v. Cotta, Erzlagerstätten II, 1861, p. 421.

the ore banded. Numerous fault slips occur between the pyrite body and the schists lying parallel to the contact. Eruptive rocks are entirely lacking.

4. *The Copper Deposit of Falun, Sweden.*

The well known copper deposit of Falun is situated close to the town on the north side of the lake of the same name, in southern Dalarne.

Careful investigations of this vast orebody were begun at a very early date, being aided by the well managed platting system, which was begun in the seventeenth century. Indeed, there is a mine map in the form of a horizonal projection on the scale of 1:500, by Olof Hansson Swart, dated 1629. Modern geologic knowledge of the Falun mine is given in the splendid monograph by A. E. Ternebohm[1], from which the following description is taken.

The country rocks in which the deposit occurs consist chiefly of fine-grained biotite gneisses, often very poor in mica, which are called granulite by Ternebohm; there are also medium-grained gray gneisses and granite gneisses, besides mica schists, quarzites, hornblende schists, granular limestones and garnet-hornblende rocks (skarn).

The deposit has a foot-wall of gray, more or less micaceous quartzite, that occurs as a thick intercalation in the gray gneiss. Besides the grains of the dominant quartz, this foot-wall rock carries biotite, cordierite, as well as scanty amounts of falunite, andalusite, magnetite, actinolite and anthophyllite. Certain stock-like bodies of this quartzite, rather sharply defined and limited by barren rock, contain varying amounts of disseminated chalcopyrite, with associated pyrrhotite, iron pyrite and sometimes also a little zinc-blende. The ore of this quality, the so-called 'hard' ore (hardmalm), constituting about two-thirds of the entire output, contains on an average 5 to 6% copper. The distribution of the ore in the quartzite is as follows: in the gray, greasy-lustrous quartzite mass, nests and stringers of the ore lie in quite irregular arrangement. The larger bodies have a breccia-like structure, more or less rounded fragments of quartzite occurring imbedded in the pyrite as in a cement. Under the microscope the finer particles of ore show no definite genetic succession. They enclose one another in all possible combinations, and are, moreover, found both in the quartz grains and more abundantly between them. At times, however, minute veinlets extend from the larger chalcopyrite grains into adjoining quartz grains. Hence Ternebohm concludes that the material for the present sulphide ores must have existed in the deposits before metamorphic

[1] A. E. Ternebohm: 'Om Falu Grufvas Geologi.' (On the geology of Falu mine.) Geol. Fören. i Stockholm Förhandl., Vol. XV, part 7, 1893.

processes changed it to the ore-bearing quartzite of to-day. The breccia-like and vein-like formations occurring at times in the hard ore are of secondary origin, a result of subsequent pressure, such as is common in the rocks of that locality.

Besides these masses of ore-impregnated quartzite, ore is largely extracted from stock-like bodies of compact pyrites, more briefly called pyrite stocks. The ore of these bodies is called soft ore, "blotmalm," and contains an average of 2 to 3% copper. These stocks are also really masses of quartzite impregnated with pyrite, though the impregnation differs from that of the 'hard' ore both in quantity and quality. Moreover, transitions from one variety to the other are found in the so-called 'half-hard' ores, which on examination under the microscope still show all the normal ingredients of the gray quartzite.

The composition of the compact pyrite masses varies. The main varieties are: quartzose, calcareous and actinolite-pyrite ores. The quartz-pyrite ore is decidedly predominant. It is essentially a granular-crystalline mixture of iron pyrite and quartz with accessory cordierite, anthophyllite, magnetite, copper pyrite, pyrrhotite, zinc-blende and in rare cases galena. For genetic considerations it is especially noteworthy that the pyrite often occurs in small crystals as inclusions, not only in the quartz, but also in the cordierite and anthophyllite. The other sulphides frequently constitute the cementing material between the grains of iron pyrite. A breccia-like structure also sometimes occurs in the 'soft' ore, in which case fragments of pyrite are enclosed by quartz, whose grains in their turn harbor minute crystals of iron pyrite. Hence the inference is that after dynamic forces had formed the breccia, a chemical regeneration and re-crystallization of the ingredients of the ore took place.

The calcspar ore is evidently a product of impregnation from limestone deposits, such as occur in this part of the mountain. The actinolite-pyrite ore, on the other hand, seems to have resulted from the pyritization of a *skarn* (granular-limestone and garnet-hornblende rocks).

Taken together the Falun pyrite-stocks form a rather irregular mass, whose core appears to be the Storgrufva stock, while to the southeast the Källorts stock, the Mans-Nils stock and the Drottning stock adjoin, and toward the west the Schultz stock and the Kräftklo stock are developed in the Luise mine. The central or Storgrufva stock, the largest of all, is 200 meters in diameter and tapers downward.

The various pyrite stocks are almost completely surrounded by so-called 'skölar.' By a 'sköl' the Falun miners understand the same thing that in the Harz is called a 'ruschel,' that is to say, a system of parallel fissures, with crushed and chemically altered material from the walls. This material varies in composition with the nature of the adjoining rock; thus at Falun chlorite, talc and amphibole skölar are distinguished, adjoining the corresponding rocks. These skölar have for the most part a crescentic course, alternately uniting and separating.

These fissures, filled with friction products, sometimes also contain ores, 'sköl malmer,' having proved, in fact, the bearers of the richest ores. Thus the richest orebody ever known at Falun was found in the Knipps sköl. It consisted of dense, perfectly pure copper pyrite, with intergrown cubes of iron pyrite. Such finds, however, always occurred only in the upper workings, which in itself points to a secondary origin.

Since October, 1881, when free gold was discovered in Falun ore by a boy, special gold ores are also extracted, a slight gold content (2 to 3 gm. per ton) having been previously recognized in the ordinary copper ore. The gold is found in delicate, white quartz strings, which at certain points occur in clusters in the hard ore, always in company with a seleniferous galeno-bismuthite. The ordinary 'selenmalm,' as the gold ore without visible gold is called, contains 10 to 30 gm. of gold (10 gm.=0.3 oz.=$6) to the ton. The richer gold ore, in which the gold is perceived even with the naked eye, may contain as much as 100 or even 300 gm. per ton ($66 to $198. The richest gold orebodies were found in the neighborhood of a much disturbed section called Mencka Vecket (Mencka fold), particularly where diorite dikes occur in the hard ore[1].

A few remarks may be added concerning these and other eruptive dikes in the Falun mine. At many points the quartzite is cut by felsite porphyry dikes, which ordinarily appear to be 'mixed' dikes, inasmuch as along each contact thin sheets of a badly altered dioritic rock accompany the main acid body of the dike. Ternebohm attributes them to different eruptions. Since recent discussion ascribes a simultaneous origin to such formations, the possibility of this genetic development is also to be kept in mind. These 'mixed' dikes, like the bedded schists, are jammed, folded and dislocated in all manner of ways, and this is especially the case with a number of narrow, independent dikes of diorite. Whole sections of such dikes have thus been torn entirely out of their connections and have been kneaded into entirely isolated lumps.

Falu Grufva is the oldest and most important mine of all Sweden[2]. Mining operations may there be traced back to the year 1220, and documents, dated as early as 1288, speak of the "Stora Kopperberget" (large copper mountain), as the mine is called. According to tradition, a herds-

[1] G. Nordenstrom: 'Fynd of gediget guld i, Falu grufra.' Geol. Fören, Förhandl., Vol. VI, p. 59.

[2] Th. Witt: 'Nagra tekniska och ekonomiska uppgifter rörande Falu Grufva.' Falun, 1896.

man discovered the reddish outcrop of the pyrite by noticing that a goat, in rolling on the ground, made a red-colored pit. For many years Falun was worked by a company with 1,200 shares, belonging for the most part to the crown. Since 1800 this has been changed into a stock company, called the Stora Kopparbergs Bergslags Aktiebolag. The great cavity called Stöten, under which mining is in part carried on by overhead stoping, was formed in 1687 by the collapse of extensive excavations. A well known incident is that of a miner named Mats Israelsson, who in 1670 was killed in the Mårdskin shaft, and whose body was found fifty years later preserved by vitriolized mine water.

The average yearly output of the Falun mine during the last decade was 400 tons of copper, 200 kilograms of silver (derived from silver-bearing blende and galena), as well as 80 to 90 kilograms of gold. The copper production in former times was magnificent, especially in the seventeenth century. About 1651 it amounted to 3,066 tons. The total output of copper is estimated at 500,000 tons, besides 15 tons silver and 1 ton gold. By means of this rich revenue, Gustav Adolf defrayed most of the cost of his campaigns.

5. *The Pyrite Beds of Norway*[1].

In four districts of Norway pyrite beds are found, which are worked for copper: (1) on the west coast of southern Norway, especially on the outlying islands; among them the well known but abandoned Vigsnäs mine, also a series of mines on Bömmelö and Veraldsö; (2) the small mines at Grimel, on the west coast of Grimeli, central Norway; (3) Trondjem district, especially the Storvarts, Kongen and Mug mines near Röros and the mines at Meraker and in the Foldal; (4) in the Sulitelma region in Nordland, north of the Arctic circle.

These deposits consist of iron pyrite with an admixture of copper pyrite. The ore contains on an average 2.5 to 3% copper. In rare instances zinc-blende and some other sulphidic ores appear, such as pyrrhotite, galena and arsenopyrite. The non-metallic minerals include quartz, which often occurs filling the entire orebody, hornblende, mica (mostly magnesium mica), diopside, garnet, more rarely feldspar, epidote, titanite, chlorite and also fluorspar. Particularly noteworthy is the occurrence of numerous crystals of tourmaline in the pyrite of Vigsnäs.

They form more or less lenticular masses conformably inter-

[1] [illegible] komster af Kise i Norge,' Christiania, 1873. J. H. L. Vogt: [illegible]-91, with review of literature, p. 157. H. Reusch: 'Bömmelöen [illegible] Vigsnäs). A. W. Stelzner: 'Die Sulitelma Gruben in nordl. [illegible], 1891. J. H. L. Vogt: 'Ueber die Kies lagerstätten vom Typus [illegible] *Zt. f. Prak. Geol.*, 1894, p. 41. O. Nordenskjöld: 'Om Bossmo Grufvors [illegible] Fören F[illegible]kholm, 1895, Vol. XVII, part 5.

calated in the country rock. The latter consists of schists, mica schists, phyllites, fibrous schists (Carbonschiefer, containing concretions arranged in the form of sheaves), quartz schists, chlorite schists, all affected by regional metamorphism, with certain bands which, according to H. Reusch (Bömmelöen og Karmöen, 1888) at Bömmelö and Stordö and elsewhere, contain various easily recognizable fossils such as *Halysites catenularia, Favosites*, etc., and hence are of Silurian age.

It is a remarkable fact that the pyrite beds within these Paleozoic strata only occur where masses of saussurite-gabbro are found.

The lenses are for the most part but a few meters in thickness, rarely attaining 20 meters, but, on the other hand, while continuing but a short distance in the strike, they may usually be traced long distances in the dip. Sometimes they have the shape of true 'ore pods' (long, narrow lenses of

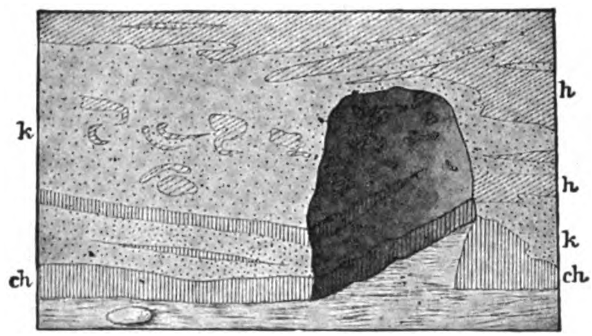


Fig. 202.—Outcrop of the pyrite bed of Mons Peter Uren. (Stelzner.)
h, hornblende schist; ch, chloritic schist; k, pyrite with inclusions of hornblende schist. (Thickness of bed 4 meters.)

ore, of uniform breadth and thickness) (see also pages 51 and 147). This pod-shaped form of deposit may be best illustrated by the example of the Mug mine at Röros, where the pyrite occurs in flat bands of phyllite, with a thickness of only 1 m. to 3 m. (3.2 to 9.8 feet), and a breadth of 100 m. to 150 m. (328 ft. to 492 ft.), while it is traceable to a depth of 1,050 m. (3,444 ft.) In the Storvarts mine, at the same locality, the corresponding figures are 1 m. to 3 m. (3.2 ft. to 9.8 ft.), 150 m. to 350 m. (494 ft. to 1,148 ft.) and 1,350 m. (4,428 ft.)

The contact between ore and country rock is often sharp, but there often is a transition zone, consisting of a schist with many conformably intercalated pyrite patches. The orebody in cross-section at times shows a banding parallel to the walls resulting from the presence of layers of somewhat different textures of ore.

Despite the general conformity of the orebodies with the schists, they occasionally, according to Vogt, cut across the banding or foliation of the country rock, as may be observed at times on the faces of the orebodies, while fragments of ore also occur in the schist, as appears from the section, Fig. 202. This figure also shows included schist fragments in the pyrite mass, and layers of schist intercalated parallel to the pyrite.

The entire mass of rock is at times strongly folded and compressed. This is particularly well shown by the large isolated iron pyrite crystals imbedded in the country rock, which are greatly deformed and have streaked and furrowed faces.

At times it looks as if the pyrite had been segregated only during the folding process, since it is found in special abundance at the points of flexure. In other cases again, pyrite layers take part in the most delicate folds, and hence must have taken part in the dynamic processes.

Very commonly striated surfaces and slickensides may be observed in the immediate vicinity of the pyrite bodies.

Finally, it is to be noted that pyrite beds quite similar to those described have sometimes been observed on slickensides in the midst of saussurite gabbro.

The saussurite gabbros, which have been mentioned several times, are now universally regarded as strongly compressed and dynamically altered intrusive masses of originally normal gabbros. In these rocks, the basic lime-soda-feldspar is completely replaced by saussurite, that is to say, a mixture of zoisite with albite. These gabbros also contain, instead of the diallage, hornblende in the form of smaragdite, as well as actinolite, chlorite, some garnet and rutile.

Concerning the origin of the Norwegian deposits and others of similar character, opinions are not yet settled. The view advocated by Stelzner and Klockmann, that the pyrite layers are sedimentary formations, still has adherents. This theory rests essentially on the fact of conformity, and an observed banding parallel to the stratification. It assumes that mineral solutions derived from the destruction of older ore deposits were precipitated by reduction through organic substances, in quiet parts of the sea, but it furnishes no explanation whatever of the constant association of the pyrite beds w[illegible]bbros.

V[illegible] that the pyrite masses were formed from [illegible] planes, following parallel planes of sc[illegible] of gabbro intrusions and accom[illegible]ood example of an analogous [illegible] the contact areas about the [illegible]nite [illegible]ia region, and he lays great stress on the fact that the walls of the pyrite bodies may occasionally be seen to cut across the schist, and on the occurrence of pyrite on slip joints and fractures in the gabbro itself, as at Storhusmandsberget, in Meraker. He imagines the infiltration of the solutions to have taken place under such great hydrostatic pressure as to overcome the pressure of folding, which otherwise must have filled the cavities with materials squeezed in during the flexure.

In 1896 Röros produced 20,000 tons of smelting ore and 16,300 tons of pyrite for export, and had a net copper output of about 600 tons. Sulitelma produced 40,000 to 45,000 tons of copper ore, namely, 9,000 tons of smelting ore and 31,000 tons of pyrite for export. The net copper output was about 400 tons. The copper production of all Norway for 1902 was 4,638 tons.

6. *The Pyrite Beds of Ducktown, in Tennessee*[1].

The Ducktown district lies in the extreme southeast corner of Tennessee, in a part of the Allegheny mountain region formed of folded metamorphic crystalline schists composing part of the Ocoee formation, which is probably of pre-Cambrian age. The deposits form lenticular orebodies, 3 m. to 120 m. (10 ft. to 393 ft.) thick, arranged along three parallel principal lines of fracturing. The deposits are intercalated in thinly foliated micaceous schists, varying in dip from 50° to vertical. Where the outer walls of the orebody can be followed closely, it is found that in many cases they are fault planes intersecting the plane of schistosity at a slight angle.

The unaltered ores, found at a depth of 20 to 100 ft., consist of a mixture of pyrrhotite, with chalcopyrite and pyrite in lesser amounts, together with quartz, calcite, actinolite and zoisite. Zinc-blende and galena occur in very small amounts. These ores form either very rich impregnations of the micaceous or hornblende schists, as in the East Tennessee mine, or they form great lenses of solid ore and are composed of bands varying from a mere film to thick masses. The rich ores contain over 7.5% copper, but the ores average about 1.88% as mined. The magnetic pyrite contains little if any copper, the chalcopyrite being the copper carrier. In the compact ore masses splinters of mica schist occur as layers and various non-metallic minerals, notably zoisite, actinolite and garnet, occur with calcspar and quartz. The actinolite (evidently derived, according to Henrich, from a

[1] H. Credner: 'Die Kupfererzlagerstätten von Ducktown,' *Berg u. Hütten Zeit.*, 1867, pp. 8–10. A. F. Wendt: 'The Pyrites Deposits of the Alleghanies.' School of Mines *Quarterly*, 1886, Vol. VII. Carl Henrich: 'The Ducktown Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, pp. 173–245. W. H. Weed: 'Types of Southern Copper Deposits,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXI. J. F. Kemp: 'The Deposits of Copper Ores at Ducktown, Tenn.' *Trans.* Am. Inst. Min. Eng., 1901.

pyroxene) forms netted aggregates filled with ore. The garnet crystals, too, are seamed by the ores, while the quartz was segregated simultaneously with the ores. The quartz also fills thin, flat, cross fissures (floors) in the beds.

Above the primary sulphide ores there was a zone of rich, black ore, the "black copper zone" varying from 0.6 to 2.4 meters thick. This consisted mainly of black copper glance, with sulphates of iron and copper, and, nearer the surface, of oxidized ores, viz., cuprite, malachite, azurite, etc., in nodules and druses, also native copper in sheets and bunches, and rarely cuproplumbite.

The black copper zone, for which the mines were first worked, is overlain by an iron gossan, 5 to 24 meters thick, consisting of sandy, scoriaceous, dense, spongy or hematitic brown iron ore, which in places formed prominent exposures.

Kemp shows the Ducktown rocks to be shales and sandstones altered by regional metamorphism into micaceous and quartzitic schists. The orebody may be, as suggested by Henrich, an altered and replaced hornblendic dike made schistose and impregnated with ores. From the association of the minerals among themselves Henrich infers that pyrrhotite and chalcopyrite were the first to be introduced, with a later introduction of the other sulphides and the quartz.

From existing remains it is inferred that the prehistoric mound-builders smelted oxidic ores in Tennessee. In 1850 the first mine, Hiwassee, was discovered. In 1853 the new area produced 808 tons of ore, with an average of 28% copper. Two companies are now operating in the district and the aggregate production for 1903 was 13,855,612 pounds copper.

Similar deposits occur in central Vermont at Copperfield and South Strafford[1]. Also at Ore Knob, Tenn. In Guerrero, Mexico, at La Dicha mine, forty miles northeast of Acapulco, a similar deposit occurs in schists. The ore consists of pyrrhotite and chalcopyrite, and is traceable for over a mile, 7,000 feet being actually exposed by development, with a thickness of 12 to 80 feet. (R. T. Hill.)

V. Cobalt Fahlbands.

1. *The Cobalt Fahlbands of Skuterud and Snarum, in Norway*[2].

The cobalt ore deposits of Skuterud and Snarum lie in the parish of

[1] W. H. Weed: *Bull.* 226, U. S. Geol. Survey, 1903, p. 189.

[2] The most important works are: J. F. L. Hausmann: 'Reise durch Skandinavien,' Vol. II, pp. 69–91. K. F. Böbert: 'Ueber die Analogie der Glanzkobalt-lagers bei [illegible]d bei Vena,' Karsten's *Archiv.*, 1832, Vol. IV, pp. 280–284. *Idem*: [illegible]odumer Blaufarbenwork in Norwegen,' 1846, Vol. XXI, pp. 207–214. [illegible]te in manuscript, 1857. Kjerulf: 'Geol. d. sudl. Norwegens,' Trans-[illegible]tt, 1880, p. 323.

Modum, in southern Norway, southwest of Tyrifjord. The country rock of the region consists of the uniformly vertical beds of crystalline Thelemarken slates, strata probably of Paleozoic age, altered by regional metamorphism. These are in the main underlain, in the area of the cobalt fahlbands, by medium-grained, very fissile biotite gneisses, characterized by an abundance of microline and sillimanite, and frequently showing a hornfels structure; subordinate intercalations occur of muscovite gneisses, various kinds of quartzite, amphibolite (mostly garnetiferous), biotite schist, salite rock and anthophyllitic and gedritic rocks. The amphibolites, which are abundant in the immediate vicinity of the cobalt deposits, form bands which it is true are mostly conformable to the schists, but do occasionally show a transverse strike; they are evidently metamorphosed gabbros and diabases. Numerous veins and irregular intrusive masses of pegmatite are also noticeable.

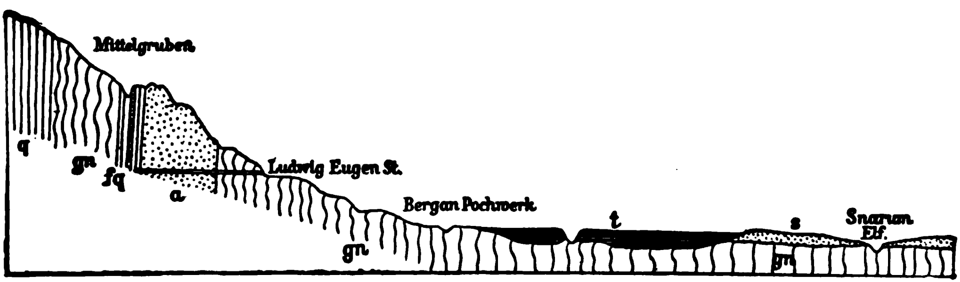


Fig. 203.—Section through the cobalt fahlbands of Skuterud.
gn, biotite gneisses, rich in sillimanite and microcline; q, quartzite; fq, fahlband quartzite, a garnet amphibolite; t, late glacial clays with fossils (*Arca glacialis* Sars); s, glacial sands and gravels.

Of the many fahlbands, only the largest is as yet of economic importance. This one is several hundred meters wide and 10 km. (6 miles) long, and runs north and south along the west side of the Simoa valley through a mountainous and mostly wooded region, from Muggerud near Skuterud northward to the region of Korsbön Höfe, near Snarum. Though a slight amount of cobalt is found in the rocks almost everywhere along this zone, which is two hundred meters wide and many miles long, yet only a few points were found rich enough in ore to work. Mines existed at Skuterud, farther north at Saastad, and finally at Devigkollen, near Svartefjeld, at Svendbye and Heggebaek. A second but small cobalt fahlband of no economic importance runs along the opposite side of the valley, past the Snarum church.

The general geologic conditions of the Skuterud mines are shown in the cross-section, Fig. 203.

These cobaltiferous fahlbands are members of the complex of crystalline schists. They follow the general strike, and usually also the dip of the gneisses, and contain disseminated cobaltic and other ores. The impregnation is most marked in a light-colored, finely granulated quartzite. This fahlband quartzite contains, besides the predominant quartz, much brown mica, and is penetrated by numerous crystals of brown tourmaline, salite granules, fibers of anthophyllite[1], rutile, zircon, graphite and metallic sulphides. Certain bands of the quartzite are especially rich in cobalt ore, and in this case the rock contains a larger amount of salite or gray-green actinolite or anthophyllite, as well as plagioclase. Cobalt ores were also found associated with a granular-crystalline or coarsely radial salite rock, containing some plagioclase, quartz and brown tourmaline; this rock appears to be secondarily transformed into an anthophyllite rock.

The most important of the disseminated cobalt minerals is cobalt glance. It is usually found in well formed crystals, included in the quartz and other minerals that form the fahlband quartzite, but also occurs within the garnets of the micaceous outer layers of the amphibolites. The cobaltite is accompanied by small amounts of arsenopyrite, chalcopyrite and pyrrhotite. The two last named minerals sometimes envelop the cobalt glance, but themselves occur as inclusions in the tourmaline and other minerals of the fahlband. Furthermore, chalcopyrite of a later generation also occurs in the interspaces of the salite rock. In rare cases pyrrhotite is accompanied by molybdenite. No veins carrying cobalt ores are known in this area. Several small quartz-calcspar veins, which occur in the fahlband zone and contain pyrite, copper pyrite and galena, are evidently of younger formation, and have nothing to do with the genesis of the cobalt rocks.

The disseminated cobalt minerals are unevenly distributed in the fahlbands. Especially rich portions are found within the workable bands, rich pay streaks which are usually only 10-20 cm., rarely up to 0.5 m. thick. They commonly consist of a mixture of quartz, actinolite, mica and the metallic sulphides, but sometimes contain considerable masses of almost pure, compact ore. The orebody sometimes cuts across the schist at an acute angle with the dip of the rock, though the strike is the same.

As a rule the rock carries but a small amount of ore. From records made in 1840, Böbert infers that the ore-bearing fahlband masses then being worked yielded an average of 3% of millable ore, which itself in turn yielded about 3% of cobalt concentrates.

[The g]enesis of these deposits is still in doubt, but it is probable that the rocks were cobalt-bearing before their regional metamorphism.

[1] [Ort]horhombic hornblende, $(Mg,Fe)\,SiO_3$.

The cobalt mines in Modum parish were discovered in 1772, and until 1813 were the property of the Crown. In time when the price of cobalt was high, they were vigorously worked. In 1838-39, according to Böbert, 3,106 centners of cobalt concentrates were obtained. Toward the end of the forties, the most important mines passed into the possession of the Saxon Bluing Works, a private company.

The description of the cobaltiferous fahlbands of Norway applies almost exactly to those of Vena near Askersund on Lake Wetter in Sweden, deposits which, because of their lower percentage of cobalt, have long been idle.

There is a resemblance between the cobalt deposits of Skuterud and those of Tunaberg in Södermannland in Sweden[1]. The cobaltite and the chalcopyrite occur in grains scattered through crystalline dolomitic limestone rather than micaceous schists. In this case, too, no conjecture can be expressed regarding their genesis[2].

2. *The Cobalt Deposits of Dashkessan in the Caucasus.*

The cobalt deposits of the Caucasus are of quite a different kind from those of the cobalt fahlbands of Norway. They resemble quite closely the ore deposits of Schwarzenberg in composition and may be regarded as a cobalt-bearing variety of that type.

The Dashkessan cobalt deposit[3] outcrops on the east slope of the Katschkar-Tschai valley, about 6 miles west of Elisabethpol, in the Armenian mountain region, south of the main range of the Caucasus and the Kura river. The mines lie about 300 m. (984 ft.) above the floor of the valley and 5,000 to 5,575 ft. above the sea. While granite rocks are said to underlie most of the Katschkar-Tschai valley, the following conditions prevail at the mines:

The ore deposit dips gently, not over 50°, and quite regularly to the southeast, and the same dip prevails in the overlying and underlying strata. The stratigraphic series, from above downward, is as follows:

4. A reddish or dirty gray-green, decomposed porphyrite, forming the outcrop; in part transformed into a very fine-grained aggregate of epidote and garnet.

[1] Erdmann: 'Beskrifning öfver Tunabergs Socken,' Stockholm, 1849. Durocher: 'Observations sur les gîtes métallifères de la Suède et de la Norvège,' *Ann. des Mines*, 1849, Vol. XV, p. 329.

[2] The mineralogically similar fahlbands of Kongberg, which are impregnated with pyrite, pyrrhotite, chalcopyrite, zinc-blende and galena, are described, together with the silver-veins of that place, on p. 275.

[3] A. Bernoulli: *Zeit.* d. D. G. G., 1867, Vol. XIX, p. 14. See also paper by G. Rose, same journal, 1868, p. 233.

3. The cobalt bed proper, on an average 0.2 m. (8 in.) thick.

2. A layer of magnetic iron ore, over 1.8 m. (6 ft.) thick.

1. A highly decomposed, light gray porphyrite, exceedingly rich in CaO and Na_2O.

The layer of magnetic iron consists mainly of finely crystalline magnetite, rarely showing large crystals of magnetite, and containing garnet, epidote, actinolite, quartz, chalcopyrite, zinc-blende and hematite; quartz, completely interwoven with hornblende spicules, and resembling the prase of Schwarzenberg, occurs mixed through the ore. The hematite forms large sheets or radial pseudomorphs after actinolite. Drusy quartz with hematite, small magnetite crystals and yellowish-green epidote occur, especially in the lower part, where they are associated with coarse calcite. Near the top the magnetite layer often shows an admixture of partly serpentinized, light greenish-yellow mineral, which proves to be a salite or a diopside.

This serpentine, together with green hornblende, chlorite, epidote, garnet and a prase-like quartz netted with actinolite spicules, forms the real matrix of the cobalt ore. Where this mass is specially rich in serpentine, it is called by the local miners pipestone, "chibush dash," because pipe heads may be carved from it when in the original moist condition. In this skarn-like mass the cobalt minerals, mainly cobaltite, occur very irregularly distributed, ordinarily in crystal aggregates, but at times in good crystals, with copper pyrite, as well as a little zinc-blende, hematite and magnetite. The cobalt ore is sometimes gathered in nest-like or lenticular bodies. Stringer-like segregations of ore were also observed in the midst of the gangue. Certain parts of the deposit consist of a granular-crystalline aggregate of barite carrying disseminated grains of copper pyrite and blende, the latter bordered and netted by films of galena.

A second cobalt deposit, probably similar, is known between Dashkessan and Bayan.

The mining operations at the cobalt ore deposit just described have been conducted since 1866 by a German firm (Siemens), and seem to have attained their greatest prosperity toward the end of the sixties. Thus in 1869, 187.5 tons of cobalt were obtained and shipped to the Saxon Bluing Works[1].

Cobalt is produced by only one mine in the United States, Mine La Motte, near St. Louis, Mo., where the cobalt is recovered as a by-product of the lead ores. The cobalt occurs in copper and iron pyrite intermixed with galena in irregular orebodies in a bed of limestone, and is found along a northeast fault. (See Mississippi Valley Lead Deposits.)

[1] 'Annales des Mines,' 1892, p. 503.

VI. Bedded Gold Deposits in the Crystalline Schists.

1. *The Gold Deposits of the Appalachian States*[1].

The Appalachian gold deposits are found in the Piedmont plateau, an upland zone between the Atlantic coastal plain and the mountain ranges of the Alleghanies. This region begins in Nova Scotia, where gold was discovered in 1861 at Halifax, and thence continues in a southwesterly direction as far as Alabama. In the Southern States the occurrence of gold was known to the early Spanish explorers. The deposits occur in crystalline schists, such as micaceous gneisses, hornblende gneisses, mica schists, hornblende schists, quartzitic, chloritic and sericitic schists, supposedly of Archean, Algonkian or Paleozoic age. In the gold areas these rocks are usually completely decomposed to a depth of 15 to 30 m. (50 to 60 ft.) into clayey masses, called by G. F. Becker saprolite.

The great majority of the deposits consist of zones containing numerous, often closely crowded quartz stringers and lenses, mostly perfectly parallel to the schistosity, but occasionally crossing it. These quartz stringers carry auriferous pyrite, and to a less extent auriferous chalcopyrite and arsenopyrite, as well as galena, zinc-blende, and in rare cases, as at Kings Mountain mine, N. C., tellurides. As fragments of the surrounding crystalline schist are not infrequently found included in the quartz, the epigenetic nature of these gold quartz stringers is beyond doubt. This conclusion is confirmed by the occurrence, rare though it be, of true fissure veins (see pages 297 and 299) of the same mineral composition. Besides the workable quartz lenses, there are also fahlband-like zones of impregnated schists, containing the ore minerals mentioned above in fine grains disseminated through the rock. These impregnated rocks are silicified.

The immigration of the auriferous solutions probably took place before Jura-Trias time, since the conglomerates belonging to that epoch also contain gold. This inference of course supposes that the gold content of these Jura-Trias conglomerates is alluvial and not introduced into the conglomerates at some later period.

Among the numerous examples, special interest attaches to the deposits of this kind near Dahlonega in Georgia, which carry tetradymite.

[1] Important publications: H. Credner: 'Beschreibung von Mineralvorkommen in Nordamerika.' *Berg. u. Hütten. Zeit.*, 1866, pp. 55, 144. Same author: 'Geogn. Skizzen aus Virginia, Nordamerika,' *Zeit.* d. D. G. G., 1866, p. 77. W. B. Phillips: 'The Lower Gold Belt of Alabama,' *Bull.* 3, Geol. Surv. of Alabama, 1892. G. F. Becker: 'Reconnaissance of the Gold-Fields of the Southern Appalachians,' *Ann. Rep.* U. S. Geol. Surv., 1894–95, Vol. XVI, p. 289. H. B. Nitze: 'The Gold-Ores of North Carolina,' *Bull.* 3, Geol. Surv. of N. Carolina, 1895. Also 'Gold Mining in the Southern Appalachian States,' *Trans.* Am. Inst. Min. Eng., 1895.

According to H. Credner, a zone of chloritic schist only 8 cm. (0.26 ft.) thick, bounded neither by surfaces of stratification nor by fissures, but quite distinct, contains many stringers of quartz, 1.5-3 cm. thick, as well as nut-shaped masses of this mineral. This quartz carries besides garnet, flakes of silvery white mica, pyrite and brown hematite, many small scattered scaly patches of light lead-gray tetradymite. Small fissure-shaped druse cavities also extend through the surrounding chloritic schist and hold native gold in botryoidal masses, penetrated by clear crystals of quartz. Aggregates of crystallized gold often hang to the schist by a mere thread. Gold is also found in the hornblende gneiss of Dahlonega, which is there found intercalated between itacalumite-like quartzite slates. In this case the gold exists in moss-like wire or scaly particles penetrating the quartz stringers and associated with bismuth telluride (tetradymite). Eckel has recently (1903) examined the gold mines of the last named locality, and finds that the veins all occur at contacts between the soft mica schists and igneous rocks, either altered schistose diorites (amphibolites) or massive granite[1].

The gold quartz beds of Faribault in Nova Scotia are another remarkable example. They are, with few exceptions, associated with anticlinical folds of the schist and quartzite, and occur at points, which in consequence of a secondary anticlinical folding, show a dome-like uparching, being thus analogous to the saddle lodes of Bendigo. Eleven such anticlinals, approximately parallel, are known east of Halifax[2]. Of the 21 arches of strata on the anticlines, 14 contain caps of gold quartz now worked, while 6 others have at least been demonstrated. The layers generally parted or slipped along the contact plane between quartzite and slate, the movement being shown by slickensides. The cavities thus formed, very gradually during flexure, were as gradually filled with the auriferous quartz, as proved by the crusted structure of the orebodies. The thickness of the anticlinal lodes thus far worked varies between 0.4 m. and 0.7 m. (1.3 ft. and 2.3 ft.). In the Golden Hill dome, some 55 different orebodies have been traced on the north side of such an anticline. For that matter, true fissure veins of identical composition are known in the region.

2. *The Homestake, South Dakota, Gold Deposits.*

Gold deposits of the Appalachian type also occur near Lead, in the Black Hills of South Dakota. The Homestake zone of impregnated schists takes its name from that of the "biggest gold mine of the world." The

[1] *Bull.* 213, U. S. Geol. Surv., 1903, p. 57.

[2] E. R. Faribault: 'The Gold Measures of Nova Scotia and Deep Mining.' Paper read before the Can. Min. Inst., March, 1899.

Homestake orebody is not a fissure vein, but a broad impregnated zone in the schists, with a course of north 34° west, cutting at a slight angle across the foliation of the schists. The ore occurs in lenses dipping east and pitching south. The orebodies near the surface appear to follow intrusive dikes and masses of rhyolite porphyry, but in depth they diverge from them and in part are associated with a greenish-colored phonolite.

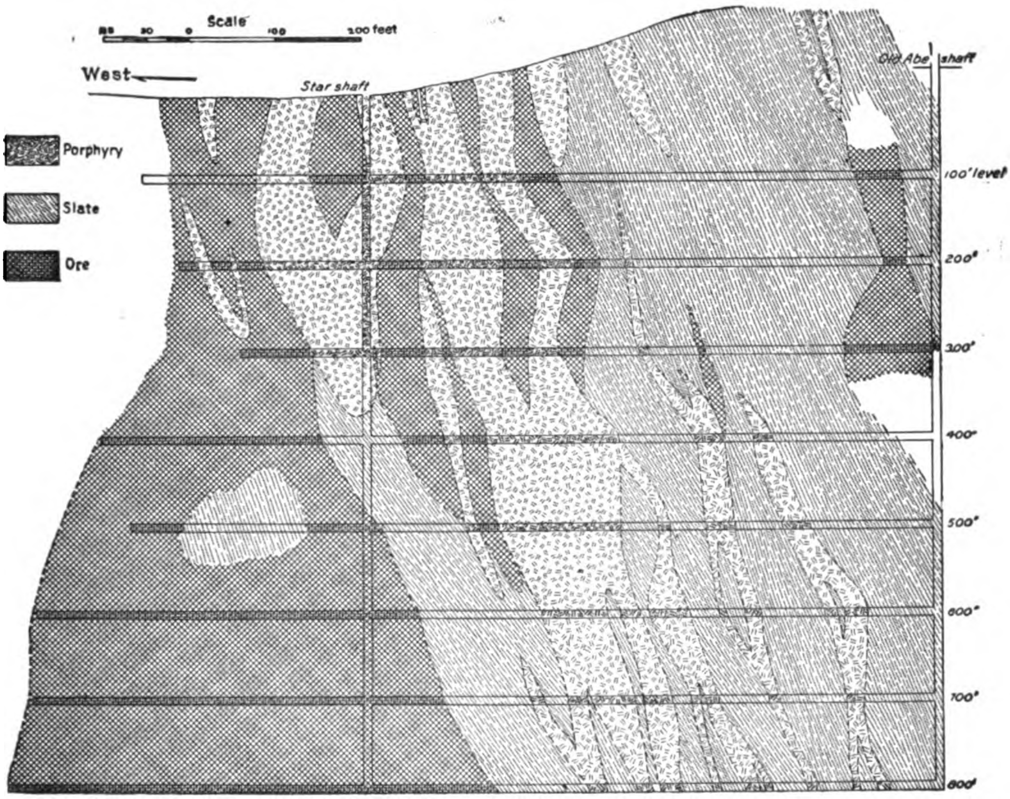


Fig. 203*a*.—Cross-section of the Homestake orebody, near Lead, South Dakota. (Emmons.)

The usual ore is made up of quartz and pyrite, with or without accessory dolomite, calcite, and arsenopyrite. Sometimes garnet and tremolite appear, but the values are independent of the accessory minerals. According to Irving[1] the ores occupy a zone of schists differing from the normal schists in a greater amount of distortion and the presence of secondary minerals. There have been several different periods of mineralization.

[1] *Bull.* 225, U. S. Geol. Survey, 1904, p. 123. 'Economic Geology of the Northern Black Hill,' Prof. paper No. 35, U. S. Geol. Survey, 1904.

The main orebody is 500 feet wide and averages $3.50 per ton. The ore after stamping is run over plates and then cyanided. This great property was acquired by the Homestake Company in 1877, and equipped with an 80-stamp mill the following year. At the present time the corporation owns 2,600 acres of mineral land, developed to a depth of 1,250 feet, and treats 4,000 tons a day in mills aggregating 1,000 stamps. The total production up to January 1, 1904, is $75,000,000, of which $20,000,000 was distributed as dividends.

3. *Other Examples of This Type.*

In South America the type occurs in Brazil, especially in the region west of the Sierra Mantiqueira[1]. In the region of Ouro Preto certain layers of sandy specular hematite only a few centimeters thick, found within the itabirites, are sometimes rich in gold, occurring in nuggets, flakes, and as wire gold. A famous example occurs at the Gongo Socco mine, which from 1826 to 1856 produced 12,887 kilograms of gold out of such zones as Jacutinga[2] (specular hematite sandstones)[3].

In Africa this class is, according to Schmeisser[4], found in the gold deposits of the Sutherland mine west of Leydsdorp, and according to Molengraaff[5] another example occurs in the crystalline schists of Barberton, both in the Transvaal. Most of the gold deposits of the so-called Gold Coast of West Africa, north and south of the Kong mountains, belong to this class. Mining was formerly carried on there in the following districts: Denkira, including Wassau, Encasse, Juffer and Commendah, Acanny, Akim, Ashanti, Adansi and Aowin. The gold-bearing conglomerates of Tarkwa in Wassau will be discussed further on. The production, formerly considerable, has now declined to an annual average of 102,000 pounds sterling[6].

This type of deposit occurs in Europe also, but apparently has not been scientifically studied with the same degree of accuracy as the American Alleghany occurrences. They occur, according to J. G. Klemm, in Spain,

[1] A. Pissis: 'Vorkommen und Gewinnung des Goldes in Brasilien,' *Berg u. Hütten. Zeit.*, 1842, p. 752.

[2] H. K. Scott: 'The Gold-Field of the State of Minas Geraes,' *Trans.* Am. Inst. Min. Eng., Feb. and May, 1902.

[3] This is regarded by Harrison as concretionary ironstone, resulting from surface decomposition of auriferous basic rocks, from which the iron is dissolved to form a surface mantle, cementing residual sand. Brit. Guiana Govt. *Report*, 1900. 'Geol. Essequibo,' etc. (W. H. W.)

[4] Schmeisser: 'Ueber Vorkommen und Gewinnung nutzbarer Mineralien in der Südafrikanischen Republik,' 1894, p. 33.

[5] G. A. F. Molengraaff: 'Géol. de la Rep. Sud-Africaine,' p. 17.

[6] *Z... ...ak. Geol.*, 1899, p. 374.

as the gold-bearing quartzites of the Sierra Guadarrama north of Madrid[1]. According to Th. Breidenbach[2], gold also occurs as minute specks impregnating schist, in the once famous Roman gold mining area of the Somedo mountains in northwestern Spain. The Romans worked only the gold-bearing schists, but did not touch the quartz veins of the region because their gold content is very low.

4. *The Gold Deposits of Zell in the Ziller Valley, Austria.*

According to A. R. Schmidt[3], the mica schists, phyllite[4] schists and talcose schists of the Ziller Valley, at the Tannenberg, Heinzenberg, and at Rohr near Zell, as well as at the Leimacher Berge, near Hippach, and thence as far as Thurnberg and Kaltenbach, contain a number of gold-bearing quartz segregations. They lie parallel to the foliation and are ordinarily accompanied by blackish-gray clay slate, finely impregnated with arsenopyrite and pyrite. These gold-bearing schist bands contain milky white or bluish quartz quite unlike the glassy quartz of barren stringers which also occur there. The individual beds can be traced only a short distance, though together they form a long and well defined zone. Most of the beds are not workable. The Vincenzi mine, on the Heinzenberg near Zell, is the only property showing extensive development. It is to be noted that, besides the nine beds which were formerly worked there, barren quartz veins are also known in the gray clay slate. The beds are parallel in strike and dip (65° to 75° south), and are from a few centimeters to 12 m. (39 ft.) thick, and lie near one another. The most important bed is the Friedrichslager, in which an orebody 120 to 140 m. wide, and extending diagonally downward, was found to be workable. This distribution of the ore in the form of shoots (Adelsvorschübe) is a proof in favor of the epigenetic origin of these deposits. For that matter these deposits do not by any means consist entirely of quartz, but mainly of schist with quartz stringers.

The values occur mostly as minute particles of native gold, finely disseminated or, rarely, in visible granules and flakes. The ordinary gold contents were, per ton:

For sifted quartz	35–122	grams.
For unsifted quartz and schist	5.2	"
For auriferous schist	1.8	"

[1] J. G. Klemm: 'Das Vorkommen des Goldes im mittleren Spanien,' *Berg. u. Hütten Zeit.* 1867, p. 125.

[2] Th. Breidenbach: 'Das goldvorkommen im nördlichen Spanien,' *Zeit. f. Prak. Geol.*, 1893, p. 20.

[3] A. R. Schmidt: 'Geognostich-bergmännische Skizzen über die Erzlagerstätten Tyrols.' *Berg. u. Hütten. Zeit.*, 1868, Vol. XXVII, pp. 9-11, 53, 54.

[4] Phyllite is a hardened metamorphosed slate.

One ton of schist, however, corresponded as a rule only to 3.8 kilog. of quartz.

The Vincenzi mine was opened in 1628. In 1858 it was sold by the crown to a company. Having been temporarily abandoned, it is to be presently reopened.

5. *Gold-Bearing Quartz-Diorite Gneiss of Mashonaland.*

At the Ayrshire mine in the Lomagunda district, Mashonaland, a dike-like mass of gold-bearing diorite gneiss occurs intercalated between hornblende and chloritic schists, about 100 ft. from a granite mass. It has a steep northerly dip, is exposed for a length of 210 meters (689 ft.) and

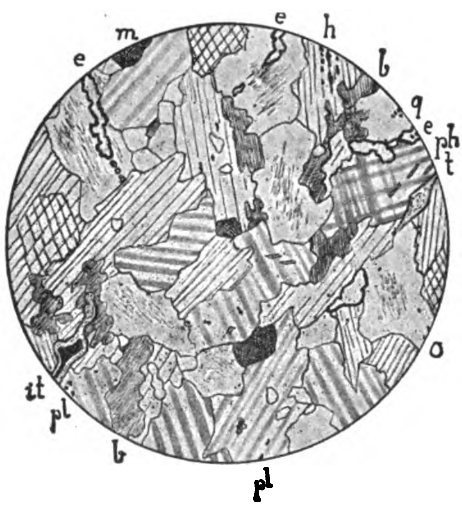


Fig. 204.—Hornblende gneiss of Lomagunda. (Enlarged 150 times in polarized light.) o, orthoclase, with inclusions of gold; pl, plagioclase; q, quartz; h, hornblende; e, epidote (all four with inclusions of gold); pn, plagioclase with hornblende microlites; il, ilmenite with titanite borders; t, titanite; b, biotite; m, pyrrhotite.

is proven for 600 ft. in depth. The vein has an average thickness of 20 ft., though but 10 ft. of this is pay ore. The average gold contact is 23 grams ($15) per ton, though this rises at times to 30 grams, and in one instance to 45 oz. ($930) per ton. The rock is a fresh fine-grained quartz diorite gneiss, of gray-green color, and faint gneissoid structure, composed of pale-green hornblende, oligoclase-albite feldspar, some quartz and accessory biotite, magnetite and epidote. The gold is intercrystallized with the other constituents, and of contemporaneous formation, but is most abundant in hornblende bands. (Spurr.)

When exposed to examination under a suitable microscope the free gold is observable in the form of rounded grains, elongated crystalline particles or minute many-sided crystals. It forms inclusions in quartz, plagioclase, orthoclase and in the green hornblende, as well as in the epidote. A light-colored pyrite, also present, apparently a non-magnetic pyrrhotite, though not the real carrier of the gold, is occasionally intergrown along the margin with gold granules. The diagrammatic thin section (combined from different parts of the slide and greatly enlarged) shows the mode of occurrence of the precious metal. Its present distribution and development was evidently simultaneous with the metamorphism of the rock. Of course this transformation effaced all evidence as to the origin of the gold[1].

6. *The Auriferous Gneisses of Madagascar.*

From specimens furnished by Superbie, A. Lacroix[2] showed that on the Mandraty river in Madagascar biotite gneisses occur, in whose constituents (quartz, orthoclase, oligoclase and biotite) tiny crystals of gold are enclosed, while besides these, independent grains and crystals of gold are abundant in the composition of the rock, which, by the way, is entirely free from pyrite. The gold is contained in the same way in the magnetite-bearing quartzites of the same region. The author just named also alludes to the occurrence of gold as a normal constituent of a gneiss in the Campanha district in Brazil, reported by O. Derby[3].

(b) EPIGENETIC ORE DEPOSITS FORMED ESSENTIALLY BY IMPREGNATION WITHIN NON-CRYSTALLINE STRATA.

(a) PYRITE DEPOSITS.

1. *The Rammelsberg Pyrite Deposit Near Goslar.*

The Rammelsberg is a mountain on the northern border of the Harz, two miles south of the old city of Goslar. It is composed of beds belonging to the Devonian, forming an overturned fold, as shown in the section, Fig. 205, after F. Klockman, from whom this description is mainly derived.

[1] J. E. Spurr: 'Native Gold original in Metamorphic Gneisses,' *The Engineering and Mining Journal*, February, 1904, Vol. LXXVII, p. 198. Also, same journal, October 3, 1903, p. 500. E. D. Berrington: 'Gold in Diorite,' same journal, July 11, 1903, p. 44.

[2] A. Lacroix: 'Sur l'origine de l'or de Madagascar,' *Comptes rendues* de l'Acad. d. Sc., Paris, Jan. 21, 1901, Vol. CXXXII, pp. 180-182.

[3] Described in this work under heading 'Pyritic Deposits in Crystalline Schists.'

According to him the deposit is intercalated in clay slates of the Middle Devonian (Goslar slates) forming the under side of the Rammelsberg anticline. The slates are overlain by the Calceola shale and, higher up, by the lower Devonian Spirifer sandstone, forming the core of the fold.

The bed is composed of lenticular bodies of compact, distinctly banded ore, whose layers are conformable with the bedding of the Goslar slate, so that all the numerous folds and wrinkles of the shale have also found expression in the ore deposit. Moreover, a great spur, or branch stringer of the orebody that runs off into the overlying strata, is generally accepted as due to a buckling or closed fold of the deposit. The compression and wrinkling are especially pronounced in the footwall of the orebody, where there are also numerous fractures extending into the ore. This foot-wall

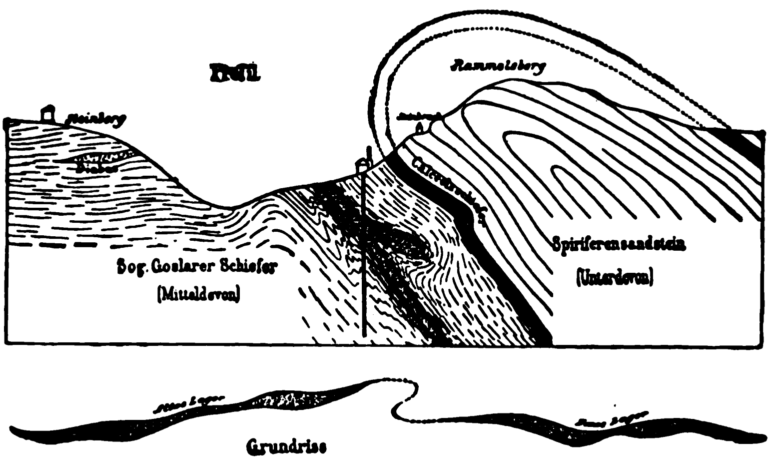


Fig. 205.—Sketch of the Rammelsberg ore deposit. (Klockmann.)
Grundriss = ground plan.

zone of maximum dynamic effect is ordinarily called Wimmer's leading stratum and is usually interpreted as an overthrust fault plane resembling the Ruscheln[1] (fault lodes) in character. Besides a forking in dip of the main orebody, forming the main deposit and its great branch, an S-shaped bend also exists along the strike as a result of the folding. (Fig. 205.) This flexure shifts the deposit to the foot-wall side. When in 1859 the orebody was recovered by a drift beyond this displacement the shifted position was called the 'new deposit.'

The deposit is normally 15 to 20 m. (49 to 65 ft.) thick, but at the intersection of the stringer it is 30 m. The known length of the old deposit is 1,200 m. (3,936 ft.) The dip is 45° southeast.

[1] G. Kohler: *Essener Glückauf*, 1894, p. 1615.

The deposit consists of distinct layers of different mineralogic composition, arranged in definite order from the hanging to the footwall, that is to say, from the older to the younger slate strata.

1. Schist-carrying pyrites, the so-called *Kupferkniest* (gangue crossed by small copper veins).

2. Dense ore, composed of an intimate mixture of copper pyrite and iron pyrite, with some arsenopyrite.

3. Mixed ores, that is to say, finely banded layers of pyrite and galena.

4. Fine-grained mixture of galena, zinc-blende, pyrite and barite, the so-called lead ores, which are:

(a) Brown ores when blende predominates.

(b) Gray ores when barite predominates.

The name banded ores is given to finely laminated, often strongly folded and wrinkled material, in which layers of slate alternate with fine layers of ore. Such banded ores often form a transition of the main ore deposit to the schist, especially on the northeast, but also quite similarly on the southeast.

The ores of the Rammelsberg deposit proper are dense and compact. In transverse vein fissures, on the other hand, the ore minerals are crystallized, including copper pyrite, galena, gray copper, zinc-blende, barite, calcite, siderite, quartz and calamine in pseudomorphs after calcspar.

In the "Alte Mann" (old man), meaning the dumps formed of pieces cemented by new materials, the secondary minerals formed in historic times include copper, iron and zinc sulphates, botryogen (a hydrated sulphate of iron and magnesia), copiapite (basic sulphate of Fe), glockerite, gypsum and epsomite.

Many authors[1] still adhere to the opinion first advanced by K. von Böhmer, that the Rammelsberg deposit is of sedimentary origin. As late as 1895, F. Klockmann tried to sustain the view that the ore had been deposited in a flat syncline of the Devonian sea bottom, which had already been filled with mud. According to him, the compact ore mass is traversed by fine layers of slate, as by "annual rings," and the reason why the lead ores occupy a larger area is that, beyond the youngest sheet, they had the

[1] Important papers: G. S. O. Lasius: 'Beobachtungen über das Harzgebirge,' 1789-1790, p. 373. C. F. Freiesleben: 'Bemerkungen über den Harz,' 1795, Vol. II, p. 75. H. Credner: 'Geogn. Verh. Thüringens und des Harzes,' 1843, p. 121. B. v. Cotta: 'Erzlagerstätten,' 1861, II, p. 103. A. W. Stelzner: 'Die Erzlagerstätte vom Rammelsberg bei Goslar,' *Zeit.* d. D. G. G., 1880, p. 809 *et seq.* G. Köhler: 'Die Störungen im Rammelsberger Erzlager bei Goslar,' *Zeit.* f. B. H. u. S. im pr. St., 1882. p. 31. A. v. Groddeck: 'Geognosie des Harzes,' 1883, p. 118. J. H. L. Vogt: 'Ueber die Genesis der Kieslagerstätten vom Typus Röros-Rammelsberg.' *Zeit. f. Prak. Geol.*, 1894, p. 173. F. Klockmann: 'Im Berg- und Hüttenwesen des Oberharzes,' 1895, p. 37 *et seq.* Söhle: 'Beitr. z. K. d. Erzlagerstätte des Rammelsberges,' *Oesterr. Z. f.* B. u. H., 1899.

widest area of the flat syncline for their distribution. The origin of the solutions he leaves undetermined, but thinks that they may possibly have been connected with the diabases.

Against this, others, and J. H. L. Vogt in particular, have advanced modern arguments on behalf of the old theory, dating back to C. F. Freiesleben, *i. e.*, that the ores penetrated into the schist rocks after their formation, Freiesleben regarding the deposit as a lode. Vogt's main arguments to support this view depend on the fact that the deposit lies alongside of a great dislocation fissure, and that there is a lack of littoral material in the country rock, although a sedimentary formation of the character postulated is only possible in a very shallow sea and in shallow bays. His reference to a possible connection of the ore deposit with the injection of Ocker granite 3 km. distant, or even with the Radau gabbro, 8.5 km. away, is regarded as of very doubtful significance.

The subsequent introduction of the ore seems to us the more likely theory. The deposition of the metallic minerals may have been by a replacement of layers of the slate, either a calcareous bed or one made up of basic silicates. A microscopic examination of specimens of the ore, which, it is true, needs to be extended, disclosed nothing at variance with that view. The real receptacle of the ores is an impure limestone, having layers of rather coarse crystalline, dark-tinted impure limestone. The ores have largely penetrated between the aggregates of carbonate crystals as an exceedingly fine veining. In the slaty layers, richer in quartz and sericite, the ore appears in thin sections to resemble the large scale sections showing parallel stripes, which may represent former layers of calcspar.

The beginning of the mining industry at Rammelsberg is ordinarily referred to the year 968. At that time, during the reign of Otho the Great, the town of Goslar already existed, having been founded, it is said, about 930. The production of the mine in 1898 was 34,804 tons of lead ore and 26,313 tons of copper ore.

2. *The Pyrite and Barite Deposit of Meggen on the River Lenne.*

This is the most important pyrite deposit of Germany, and it is of special interest for the reason that in this case one part consists of iron pyrite and another part entirely of barite, these minerals replacing each other along the same bed.[1]

The ores occur in a bed 10 ft. thick, that is, conformably inter-

[1] M. Braubach: 'Der Schwefelkiesbergbau bei Meggen an der Lenne,' *Z. f. d. B. H. u. S. im preuss. St.*, 1888, Vol. XXXVI, pp. 215-222. R. Hundt: 'Das Schwefelkies- und Schwerspathvorkommen bei Meggen a. d. Lenne,' *Zeit. f. Prak. Geol.*, pp. 156-161; with list of older works. Denckmann: Kurze Mitth. *Zeit.* d. D. G. G., 1900, p. 112.

bedded in the Middle Devonian strata, forming the Attendorn-Elsper synclinal basin, here forming a pronounced syncline with a steep southeast and a less inclined northwest flank. The latter flank is accompanied at the village of Meggen by two other troughs, whose connection with each other, like that with the main syncline, has been destroyed by erosion. The chief syncline has been traced along the strike for a distance of 5 km. Subordinate folds occur repeatedly in the larger synclinal basin, as well as a series of small transverse displacements (see section, Fig. 206).

Underlying the deposit, which averages 3 m. (10 ft.) and is at most 8 m. (26.2 ft.) thick, are graywacke slates (Lenneschiefer). Overlying it are dense nodular limestones carrying fossils (*Prolecanites*) and inclusions of iron pyrite. These limestones are in part dolomitic, and are overlaid by clay slates with false schistosity.

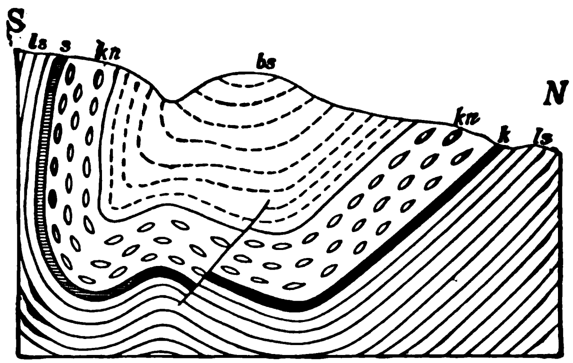


Fig. 206.—Section through the pyrite and barite deposit of Meggen. (Hundt.)
ls, Lenne slate; kn, nodular limestone; bs, Rüdesheim slates; k, iron pyrite; s, barite.

In the middle part of the syncline the deposit consists of pyrite; at the south and east of barite. The line of division between the two is sharp; there is no middle zone with a mixture of the two ingredients or with a thinly stratified alternation of the different ores. The only transition is where the pyrite at first appears as a narrow, hardly perceptible clay coat along the foot-wall, increasing in thickness more and more, until finally it has entirely replaced the barite. While at the outcrop on the Lenne near the village of Meggen only barite is found, in one of the lateral synclines these transitions, with barite at top and iron pyrite at bottom, may be traced to a distance of about 100 m. (328 ft.)

The iron pyrite is distinctly stratified, occurring in fine layers, which often show the same fine wrinkling as the adjoining slates. In some parts it possesses a peculiar structure, resembling oolite. Round granules of ore, varying in size from that of a poppy seed to that of a grain of millet, lie closely packed together. Some of these grains are hollow, and show ring-shaped figures in thin sections, the center of the grain and the interspaces between them being filled with dark barite. The barite shows, on the contrary, both to the naked eye and in thin sections, a massive structure. Under the microscope, it has an exceedingly fine-grained crystalline structure, with numerous brown flakes of bitumen scattered between the grains. An important structural feature is the presence of forkings of the pyrite layer, like those of the Rammelsberg deposit, but on a smaller scale. Such features are assumed to be due to faulting, by which barren rock is brought against the end of the lode, as shown in Fig. 206.

The iron pyrite composing the deposit is colored blackish by organic ingredients. Layers of dark brown dense zinc-blende occur mingled with it, so that the ores contain on an average 8% of zinc, for which reason the pyrite beds are worked for zinc. On the contrary, the proportion of copper pyrite and galena present is trifling. The finely granular crystalline barite, blackened by organic matter, contains about 2% of strontium sulphate

Denckmann conjectures that the Meggen deposit is an alteration product of the Stringocephalus limestone, which is greatly thinned at this point.

In 1900 the Sicilia and Siegena mines at Meggen yielded 145,122 tons of pyrite.

3. *Pyrite Beds in the Paleozoic Rocks of the Austrian Alps.*

In the Austrian Alps, several pyrite beds of this kind occur in Paleozoic schists. We will mention only two examples.

At Kallwang, in Upper Styria, according to R. Canaval[1], the Schatzlar graphitic schists (Lower Carboniferous) contain an interbedded mass 0.3 m. to 1.2 m. thick, traceable for 3,500 m. (2.1 miles) along the strike and developed for 300 m. (984 ft.) in dip. The ore consists mainly of pyrite, with associated pyrrhotite, chalcopyrite and some arsenopyrite. The copper pyrite occurs in workable amount in the upper part. In this part it encloses large cubes of pyrite. Copper mining, which is known as early as 1469 at this place, ceased in 1867.

Similar deposits are worked in the Walchern Graben, near Oeblarn, Upper Styria. According to Söhle[2], micaceous clay schists, probably of Silurian age, contain two beds of pyrite-carrying copper pyrite, pyrrhotite and some galena, with some quartzose gangue. The mine was reopened in 1897 and is still worked.

[1] R. Canaval: 'Das Kiesvorkommen von Kallwang,' etc. *Mitth.* d. naturw. Vereins für Steiermark, 1894.

[2] Söhle: 'Ueber den Kiesbergbau bei Oeblarn.'

On the other hand, the Styrian silver-lead deposits found in the Devonian schists of the region of D.-Feistritz-Peggau, Frohnleiten, Ubelbach, and Thalgraben, near Gratz, are of different character. They consist essentially of silver-bearing galena and zinc-blende, with quartz, calcite, witherite and barite, and though formerly described as beds, they must, as a result of the detailed studies made by W. Setz[1], be accepted as bedded veins of the carbon-spathic-lead group.

The pyrite deposit of Agordo, in the Venetian Alps, was formerly a great producer, but is now closed down[2].

From former reports it is known that this famous orebody, whose form has been compared by E. von Cotta to that of a flattened sausage, 4 m. to 80 m. (13 ft. to 262 ft.) thick, extends to a depth of 460 m. (1,508 ft.) and is surrounded on all sides by sericitic schists of undetermined age. The orebody consists of compact iron pyrite, containing on an average hardly 2% copper, and carries also some argentiferous blende, galena, arsenopyrite, as well as quartz and calcspar. Rich copper ores also occur, with 2 to 8% and rarely 8 to 30% copper. As late as 1880 Agordo produced 14,872 tons of ore. A similar deposit has lately been developed at Vallimperina, in the same district[3].

4. *The Pyrite Deposits of Huelva, in Southern Spain and Portugal*[4].

The Sierra de Aracena forms a western continuation of the Sierra Morena, and like it consists of crystalline schists. This range is succeeded to the south by a northwest-southeast zone of metamorphosed Paleozoic rocks, part of the beds being known to belong to the Silurian and Culm, while the age of other parts has not yet been positively determined. The strata are nearly vertical, and contain intercalated sheets or dikes of porphyry varying from quartz porphyries to diabase porphyrites. They are not confined to any definite horizon, and hence it cannot be maintained, as Klockmann tried to do, that they are effusive flows. The presence of ac-

[1] 'Die Erzlagerst. d. Geg. von D.-Feistritz-Peggau,' etc., *Zeit. f. Prak. Geol.*, 1902, pp. 357-378, 393-414.

[2] B. v. Cotta: 'Agordo,' *Berg u. Hütten Zeit.*, 1862, pp. 425-427. B. Walter: 'Beitrag zur Kenntniss der Erzlagerstätte von Agordo,' *Oesterr. Z.* f. B. u. H., 1863, pp. 114-119. A. St. Schmidt: 'Geogn.-bergm. Skizze über den Kiesstock zu Agordo,' *Berg u. Hütten. Zeit.*, 1867, pp. 240-241.

[3] 'Revista del Servizio Minerario nel, 1894,' p. 293. (Cited from Phillips-Louis.)

[4] Literature: Ferd. Römer: *Zeit.* d. D. G. G., 1873 and 1896. Gonzalo y Tarin: 'Descripcion física, geológica y minera de la Provincia de Huelva,' Madrid, 1886-88, Vols. I-III. L. de Launay: 'Mémoire sur l'industrie du cuivre dans la région d'Huelva,' *Ann. d. Mines*, 1889. With bibliography. F. Klockmann: 'Ueber die lagerartige Natur der Kiesvorkommen des südlichen Spaniens und Portugals,' *Sitzber.* d. k. preuss. Ak. d. W., Berlin, 1894. J. H. L. Vogt: 'Das Huelva-Kiesfeld in Südspanien und dem angrenzenden Theile von Portugal,' *Zeit. f. Prak. Geol.*, 1899. pp. 241-245. Gregory, *The Engineering and Mining Journal*, Feb., 1905.

companying tuffs, described by him, is as yet unproven. Towards the south the slates pass beneath a cover of Tertiary formations characteristic of the coastal area, while towards the east the slate belt terminates in the sharp fault scarp of the Guadalquivir valley. The orebodies occur intercalated in the slates, and are mostly pyrite lenses, of which more than fifty are enumerated, mostly at or near the contact with the dikes of porphyry, with the presence of which they are evidently closely connected. They are found in a zone about 200 km. (120 miles) long, but are especially well developed in a strip about 80 km. (48 miles) long and 20 km. (12 miles) wide, runnine east and west, in the Spanish province of Huelva and the Portuguese province of Alentejo, between Rio Tinto and San Domingo. The San Domingo mine, as well as La Zarza and Tharsis mines, which lie nearer the center of this zone, are the principal producers of the district, their product

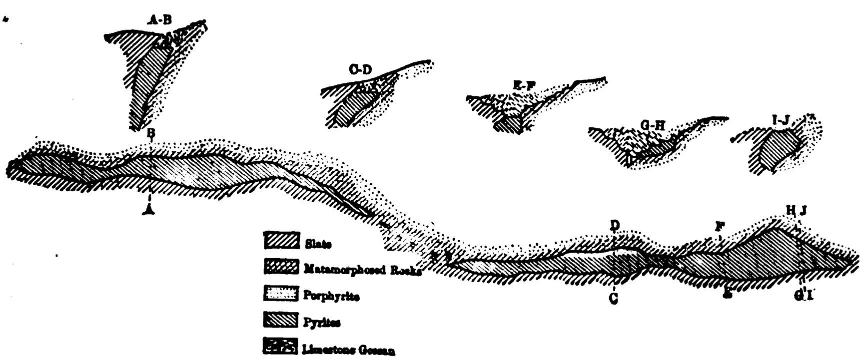


Fig. 207.—Plain and cross-sections of Rio Tinto orebodies, Huelva, Spain. (Gonzales.)

being shipped through the port of Huelva, in part also down the navigable Guadiano river and by way of Villareal.

The deposits are lenticular in shape and very thick, the Dionisio bed being 150 m. (492 ft.) across, but they often wedge out within a distance of a few hundred meters, both in strike and in depth. The accompanying cross-section, Fig. 207, after Gonzales, gives an idea of the relation of the ore lenses to the schist and porphyry. The horizontal cross-section of the compact pyrite mass of the largest lens, Dionisio, is about 60,000 to 70,000 square meters, and the entire area of pyrite deposits of the Huelva district is estimated by Vogt at about half a million sq. m., while the total pyrite mass which nature had concentrated here, before it was depleted through erosion and mining, is estimated by him at 1,000 million tons at least. The pyrite is mostly compact, finely crystalline and exhibits frequently a banding or stratification parallel to that of the slate.

The Iberian pyrite consists predominantly of pyrite with but little quartz and with a little copper pyrite. The average copper content varied during the last ten to twenty years between 2.6 and 3.2%. The amount of arsenic averages 0.2 to 0.6%. At one mine, Aguas Tenidas (Confesionario) the pyrite is free from copper and arsenic. It is notable that the amount of copper generally decreases in depth. At the Domingo deposit, for example, the copper content close below the gossan was about 4 to 5%; at a depth of 60 to 70 meters it had decreased to about 2%, at 100 m. to about 1.5%, at 130 to 140 m. to about 1%. This no doubt is due, for the most part, to the fact that the original copper content of the gossan zone, usually 10 m., at times 50 m. thick, was dissolved and then redeposited in fissures directly below the gossan, in the form of copper glance, bornite and chalcopyrite. It was this network of narrow secondary copper ore lodes that the old Romans followed with their mining operations. Directly below the gossan, in a mine, North bed No. 2, at Rio Tinto, is an earthy zone, 1 to 2 decimeters thick, with 15 to 30 grams gold and 1¼ kg. silver per ton, a concentration of the minute amount of the precious metals in the pyrite leached out in gossan formation and redeposited.

Old implements in the mines prove that the mining operations in the Huelva district were carried on by the Phœnicians, who came to Spain in the 11th century B. C. The Romans have left traces of very extensive work. In the 8th century all the work was stopped, and even after the expulsion of the Moors it remained insignificant, until energetically resumed about 1850. In 1898 and in 1902, the mines produced the following amounts of copper, in metric tons:

	1898.	1902.
Rio Tinto	34,244	36,041
Tharsis	12,192	6,817
San Domingo	3,658	3,386
Sevilla	813	462
Other mines	3,170	5,071
Total	54,077	50,767

The ore averaged 2.517% in 1902.

These totals, in view of the low copper percentage, imply an enormous production of pyrite, which for the total Huelva district amounted in 1893-1896 to 2,500,000 tons in round numbers. In the eighties, the Huelva district supplied between 1/5 and 1/4 of the copper production of the whole world, in 1897 only 1/7, having been meantime distanced by Montana and Michigan. According to Vogt, the Iberian copper production has now reached its climax, while the production of pyrite is still increasing.

5. *The Mount Lyell Gold-Silver-Copper Deposit.*

Near the west coast of Tasmania, on the north slope of Mount Owen, there is a zone of soft mica schists, called pyrophyllite schists by some writers, which contains bands of conglomerates and quartzite, as well as numerous stringers of slightly auriferous pyrite. The Mount Lyell pyrite bodies lie in these schists along the conglomerate contact. The orebody is 250 ft. thick and 620 ft. long on the surface and down to the 4th level, but grows smaller, and 300 ft. below is about 170 by 360 ft. The limonite gossan was from 1880 to 1890 worked solely for free gold ($20 to $25 gold and 20 to 25 oz. silver per ton), and the real importance of the deposit was only recognized when, some years later, pyrite was encountered and opened up. The primary ore consists of granular crystalline pyrite with interspersed copper pyrite and has an average content of 0.66 to 4.5% copper, as well as some 62 grams (2 oz.) silver and 4.5 grams gold ($3) per ton. An analysis of this "poor ore" communicated to A. W. Stelzner by O. Schlapp in 1893 showed:

Fe	41.06
Cu	4.81
Pb	trace.
As	trace.
Ag	0.01
Au	0.0005
S	50.41
$BaSO_4$	3.81
SiO_2	0.25
	100.3505

The rich ores occur in a quartzose mass along one wall. This ore contains crystalline pyrite, nests and stringers of coarse-grained copper pyrite, bornite, stromeyerite, sulphides of silver and copper, gray copper and some galena. Some samples consisted in part of fine-grained, more rarely scaly barite. Others carried nests of barite and quartz, as well as cavities filled with an ocher containing 3.47% Ag (Kolbeck) and traces of gold. Domeykite was present as a rarity.

These rich silver-copper ores are probably secondary concentrations immediately below the gossan proper. The principal mine, the Mount Lyell, yielded 3,608 tons copper, 341,346 oz. silver and 11,681 oz. gold in 1902.

6. *The Copper Deposits of Iron Mountain, California.*

The copper deposit of Iron Mountain, in Shasta County, California. is in many respects similar to the preceding example. It is one of the many copper deposits occurring in a crescentic area on both sides of Sacramento river (Shasta County copper belt)[1].

The copper belt of Shasta County, California, contains two mines of importance, viz.: Iron Mountain and Bully Hill. The Iron Mountain mine lies west of the Sacramento Valley, near Redding. The orebody is covered by a mass of limonite 100 feet thick, which was for some years worked for its gold and silver contents. The deposits consist of two elongated flattened lenses, the first on Iron Mountain 800 feet long, and 100 to 400 feet wide, worked for 600 feet in depth. The Hornet orebody is narrow, but longer. These bodies occur in a northeast-southwest shear zone. The dip is vertical or steeply northwest, the orebodies pitch northeast. The ore consists of fine-grained pyrite, with chalcopyrite intimately mixed with it. Zinc-blende occurs in streaks, and often gives the ore a schistose look, such ores occurring adjacent to the schistose metarhyolite. The walls of the orebody show slickensides with sericite selvages in some places. Small transverse faults traverse the ore. According to some observers, the two orebodies are faulted parts of one mass in an altered slaty rhyolite (metarhyolite), a rock remarkable for its high soda and low potash content.

The Bully Hill district is 25 miles northeast of Redding. The orebodies occur in three shear zones in igneous rocks. The common country rock is a metarhyolite (*i. e.,* metamorphosed rhyolite), rich in porphyritic quartz. At the Bully Hill mine, the rock most intimately associated with the orebody is a metabasalt rich in soda, forming a dike cutting the other igneous rocks and Triassic slates. The shear zones are limited, none being traceable over a mile. They vary from a few inches to 20 ft. thick, run a little east of north, and dip at a very high angle to the west. There are three parallel zones, a few hundred feet apart at Bully Hill, two of them mineralized. The west lode is in the metarhyolite forming Bully Hill. The other is in the metabasalt, near the outcrop, but follows the dike contact for 500 ft. in depth. The orebodies are lenticular and sheet-like masses, varying from the size of a nut to lenses hundreds of feet long and nearly 20 feet thick. These are irregularly distributed through the crushed and more or less impregnated mineralized rock of the shear zone. The longer axis usually pitches north. The gossan varies in thickness and extends downward along fissures. It contains gold and silver and copper oxide and carbonates. The primary ore consists of pyrite, with some chalcopyrite and sphalerite in a gangue of barite. The barite is rarely abundant and often so finely disseminated as to be invisible.

Secondary enrichment of chalcocite occurs beneath the gossan and in

[1] The description of the locality is re-written by W. H. W. from recent publications by Diller and others. 'Copper Deposits of Redding Quadrangle, Cal.,' *Bull.* 213, U. S. Geol. Survey, 1903, p. 129. Also *Bull.* 225, 1904, p. 169.

fissures and nests in the primary ore beneath it. Bornite and chalcopyrite also appear as secondary, as well as primary ores.

7. *Mesozoic and Cenozoic Pyrite Beds.*

In Southern France, west of the Rhone, and northeast of Alais (Card), there is a bedded pyrite deposit near St. Julien de Valgalgues. It is 1 to 12 meters thick, and lies between the Lias and Doggen limestone. The presence of pyritized fossils in the bed is correctly interpreted as proving the origin of the deposit by mineral springs.

Still younger deposits of iron pyrite occur in the Upper Cretaceous of Wollin Island. The beds of pyrite concretions in the Lignite formation of the Tertiary may also be mentioned here.

(β) PERMIAN AND YOUNGER BEDDED DEPOSITS OF COPPER.

The Copper Shale of the Zechstein Formation.[1]

The copper shale (kupferschiefer) at the base of the Zechstein formation of Germany is one of the formations of greatest geologic interest and economic importance known. First of all it attracts attention by its wide distribution, which is remarkable even for a stratified ore deposit, extending as it does some 200 kilometers (120 miles) from east to west and some 100 to 150 km. (60 to 90 miles) from north to south, through the whole of central Germany, from the Saale to the eastern edge of the Rhenish schist area. The outcrops of this copper shale bed extend all around the southern Harz, and enclose most of the Thüringerwald. Similar formations, perhaps not of this identical geological horizon, appear at Riechelsdorf, between the Werra and Fulda. Other beds emerge from beneath the recent volcanic area of the Kassel region at Frankenberg and Stadtberge, at the boundary of the Rhenish schist mountains, and finally pass around the northern

[1] J. C. Freiesleben: 'Geogn. Beitrag zur Kenntniss des Kupferschiefergebirges,' etc., Geognost. Arbeiten, Vol. I–IV, Freiberg, 1807-1815. A. F. v. Veltheim: 'Ueber das Vorkommen der metallischen Fossilien in der alten Kalkformation im Mansfeldischen und im Saalkreis,' *Karsten's Archiv*, 1827, Vol. XV, p. 98 *et seq.* B. v. Cotta: 'Erzlagerstätten,' 1861, Vol. II, pp. 106-111. Schrader: 'Der Mansfelder Kupferschieferbergbau,' *Z.* f. d. B. H. u. S. im preuss. St., 1869, Vol. XVII, p. 251. F. Beyschlag: 'Geol. Karte der Mansfelder Mulde,' 1893. O. Speyer: 'Zechstein des westl. Harzrandes,' *Jahrb.* d. k. preuss. geol. Landesanst., 1880, p. 80. J. H. Kloos: 'Zechstein am nordwestl. Harzrand,' same journal, 1891, p. 126. Th. Liebe: 'Zechstein von Gera,' *Z.* d. D. G. G., 1855, p. 406. H. Bücking: 'Zechstein von Schmalkalden,' *Jahrb.* d. k. preuss. geol. Landesanst., 1882, p. 29. H. Pröscholdt: 'Zechstein am der Südosts. des Thür. Waldes,' same journal, 1886, p. 165. H. Loretz: 'Zechstein am westl. Thür. Wald.,' same journal, 1889, p. 221. 'Die Geschichte des Mansfeld'schen Kupferschieferbergbaues und Hüttenbetriebes,' Eisleben, 1900.

Spessart at Bieber, much farther south. The copper-bearing strata do not, it is true, show everywhere quite the same development and do not always carry a workable amount of metal. Their typical development as an ore deposit is at Mansfeld, on the southeastern edge of the Harz, the oldest and most famous copper mining district of Germany.

In the Mansfeld area the Zechstein formation rests unconformably on the Rothliegende[1], consisting essentially of red sandstones and conglomerates, the topmost layer of which, 1 to 1.5 meters thick, has been bleached, and hence is called Weissliegendes. The Zechstein is overlain by the Bunter sandstone. The formation is subdivided as follows:

Upper Zechstein	8. Reddish or bluish clays with dolomite, gypsum, rock salt and potassium salts.	
Middle Zechstein	7. Fetid bituminous limestone.	
	6. Crystalline granular (Rauchwacke) and fine powdery (Asche) dolomite, 45 m.	
	5. Gypsum.	
Lower Zechstein	4. Zechstein limestone	.5–30 m.
	3. Marly limestone	0.75–1 m.
	2. Hanging-wall bed (Dachklotz), a marly limestone crumbling into polygonal pieces when exposed to the air	0.25 m.
	1. The copper shale bed	0.5–0.6 m.

The copper-bearing rock is a bituminous, blackish marly shale with a greatly varying amount of copper. It possesses a fine slaty texture and is so hard that it sometimes rings when hammered. The rock contains an abundance of fossils, especially more or less mineralized casts of heterocercal ganoid fishes, particularly *Palaeoniscus freieslebeni* Ag., more rarely of *Platysomus striatus* Ag. and *Acrolepis asper* Ag. Further proof of its marine, non-lacustrine formation is furnished by the shells of *Lingula credneri* Gein, a brachiopod; it also holds water-borne ends of branches, fruits and leaves of two conifers, of *Ullmannia bronni* Göpp., and still more frequently of *Voltzia Liebeana* Gein.

The chemical composition of the copper shale may be judged by the limiting values of four analyses made by Scheerer of different samples of the unroasted material:

Silica	29.22–38.42
Alumina	11.28–15.93
Lime	10.93–14.39
Magnesia	2.25– 4.53
Carbonic acid	7.02–13.51
Iron	0.85– 3.31
Copper	2.01– 2.93
Silver	0.015–0.021
Sulphur	2.15– 4.97
Bitumen as loss in igniting	9.89–17.21

[1] "The name Rothliegende or rather Rothtodtliegende (red layer or red dead layer) was given by the miners because their ores disappeared in the red rocks below the Kupferschiefer." (Geikie.)

Zinc, lead, manganese, nickel and cobalt were not determined. In thin section under the microscope the rock shows a very fine sedimentary structure. Bright flakes with numerous clastic quartz grains and cross placed muscovite leaves occur between dark brown transparent layers rich in bitumen. The arrangement of the angular particles of ore conforms to this laminated structure.

The copper shale measure may be divided by its external appearance into several thin layers, to which the miners long ago gave distinctive names. The names used in the different districts are given in the following table:

	Hettstedt-Gerbstedt.	Eisleben.	Sangerhausen.
9	Oberberge.	Dachberge.	Noberge.
8	Noberge.	Noberge.	....
7	Lochberge.	Kopf { Ober- / Unter- }	Unterwand.
6	Kammschale.	Kammschale.	Schieferkopf } about
5	Kopfschale.		.... }
4	Schieferkopf { Ober- / Unter- }	Grobe Lette.	Blattschiefer. } 10 cm.
3	Lochschale.	Feine (Loch) Lette	Schramschiefer } 5–6
2	Lochen.	{ (Wanting.)	.... }
1	Liegende Schale.		Erzschiefer. } cm.

The rock of the lowest bed is clayey and soft. In the coarser middle division, the Kopschale and Kammschale, but especially the latter, show a well marked cross fracture, owing to their strings of gypsum. Finally, the layers of the upper division grow coarser in texture and grayer in color upward, heavier and more regularly fissile.

"The mineral content of the ore bed appears as a rule in the form of what is called *speise,* that is to say, it is disseminated through the rock in the form of very fine dust particles, which on cross fracture show a metallic lustre. The color is either golden yellow, indicating the prevalence of copper pyrite, or violet and copper-red, from the prevalence of bornite; more rarely it is steel-gray (indicating copper glance), at times yellow (indicating the prevalence of iron pyrite), at times lead-gray (indicating lead glance)." (From the company's publication.) Besides the sulphur ores just named, the speise (flawy earth) contains also argentite, zinc-blende, copper-nickel, cobaltic pyrite, all in very small amounts and in minute particles. Chemical analysis has also demonstrated the presence of minute quantities of manganese, molybdenum and sélenium. Besides the speise, the copper schist also contains fine stringers of ore, mostly parallel with the stratification, and consisting of bornite and glance, while the bedding planes show stains of copper glance, bornite, copper pyrite and native silver, also here and there stains and granules and nodules of ore, called 'Erzhiecken.' As a curiosity, the scaly coat of a fossil fish (*Palæoniscus*) was found coated with native silver, while ordinarily the coating on fish impressions consists merely of copper pyrite and iron pyrite. For that matter, it is not these striking concentrations of ore that determine the paying quality of the rock, but the contents of the speise.

Though the entire bed is copper-bearing, yet the paying ore is found as a rule only in the lower layers as far as the Kammschale, inclusive or exclusive of the latter. With the decrease of bitumen from that layer downward the ore content also decreases. Only in rare cases does the 'Kopf' also contain paying ore, so that the thickness of the paying strata on the whole is only 3.15 to 4.72 in., rarely 3.15 to 6 inches.

In the Sangerhausen district, the bed beneath the copper bed, that is the uppermost layer of the Weissliegende (a bleached red conglomerate), which has a thickness of ½ cm., sometimes 3 cm., is so rich in copper that it is mined under the name of 'sand ore' containing as much as 5 or even 10% of copper. Farther west, beginning between Sangerhausen and Steine, a layer of calcareous conglomerate is intercalated between the red conglomerate and the copper shale. This thin layer is also copper-bearing, sometimes in paying quantities, and is called zechstein conglomerate and locally shares the name Weissliegendes.

As already stated, the ore and metal content of the copper bed is not uniform throughout the region underlain by it. While in the Mansfeld district a 2 to 3% ore with ½ pound of silver in a centner of copper (5 kilograms silver per ton of copper) has since olden time been regarded as an average metal content, there are many exceptions. Thus, for example, the slates of the northern part of the district, those near Hornburg, contain hardly 1.5% copper. Outside of the Mansfeld area the mineral content decreases until the rock is completely barren. On the other hand, the miners have long been familiar with the fact that the copper content increases considerably near transverse fault fissures, called Rücken (ridges), and in the neighborhood of strongly folded zones, and that the enrichment extends upward to the higher layers of the measure, the Dachberge and the Faule, which in such cases also yield pay ore. The only exception is in the Hettstädt area, where the fissures are said to have an unfavorable influence on the metal content of the ore. The fissures themselves are either devoid of metal or contain rich ores, especially copper and nickel ores.

The section, Fig. 208, shows the dislocations found so frequently in the

Mansfeld copper 'schist,' and which are a very important feature. These dislocations consist of fissures called Sprügen (cracks) or Rücken (ridges), forming an angle with the strike of the measure, together with many folds and overthrusts parallel to the principal strike, and saddle-like elevations or 'mountains' (Bergen). Very often trench-like depressions have occurred between parallel cracks, such as the great Aa Fletzgraben (stratum trench) near Eisleben.

The Mansfeld copper schist mining works are said to have been begun in 1199 or 1200 at the town subsequently called Hettstedt. The barons of Mansfeld were probably granted the mining works as a fief only in 1364. In the 15th century the old records state the yearly production to have

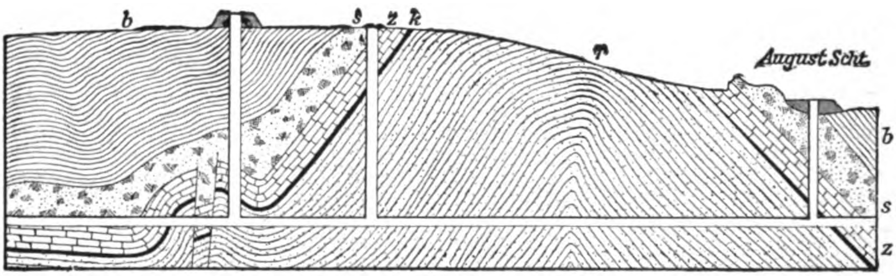


Fig. 208.—Profile of the eroded saddle (anticline) in the Tiefthal area of the Mansfeld district. (Schrader.)
b, Bunter sandstone; a, fetid stone and 'ashe'; z, Zechstein limestone; k, copper shale measure; r, Rothliegendes.

been over 20,000 hundredweight of copper. After the sequestration of the estate about 1570, and later during the Thirty Years' War, but little mining was done and the property was practically idle, which caused it to be thrown open to the public in 1671. Accordingly, in 1674, work was resumed by several corporations, which were in 1852 consolidated as the Mansfeldschen Kupferschiefer Bauenden Gewerkschaft, which is still flourishing. On June 12, 1900, the Emperor attended the 700th anniversary of the foundation of the Mansfeld mining industry.

The copper production, which for many decades has been steadily rising, was 19,050 tons in 1902; from 1779-1902 it was 476,000 tons. During its entire existence the Mansfeld mine has yielded about half a million tons of copper. The ore has averaged 27.76 kg. copper and 0.154 kg. silver.

[illegible]nesis of the copper ore of this formation, and the [illegible]e fault vein at Saalfeld, the reader is referred to [illegible]age 2[illegible] At this locality, as well as at the cuprifer- [illegible] and Schmalkelden, on the edge of the

Thüringerwald, there is everywhere a significant and constant association of ore-bearing copper strata and ore-bearing fissures.

That the copper schist, considered as a mere sediment, is of little importance for its copper content, is shown by the totally different development of the copper-bearing Permian near Frankenberg in Kurhessen, where the copper ores occur in entirely different strata.

The copper-bearing Permian strata at Frankenberg[1], according to A. Denckmann, embrace the following beds:

4. The younger conglomerates.
3. The Permian sandstones with the Geismar copper clays.
2. The Stäteberg measure.
1. The older conglomerates.

The older conglomerates consist of red-brown sandstones with pebbly layers. In some parts the sandrock contains much feldspar and iron, with a calcareous or dolomitic cement. The "Stäteberg" formation cannot be accurately discriminated either from the conglomerates or from the overlying Permian sandstones, but must be regarded as a local, highly calcareous formation at the base of the last-named strata. Petrologically, it is composed of limestones, light-colored marls, clays and calcareous sandstones, with intercalated conglomerates. A characteristic feature is the presence of remains of plants, of gastropods, and of lamellibranchs, especially *Schizodus, Aucella, Gervilia, Pleurophorus,* etc. In connection with these organic remains, impregnations with copper ores and galena are to be observed.

The overlying strata, the Permian sandstones, attain a total thickness of at least 70 m. (229 ft.). They consist of reddish brown, in part bleached, highly feldspathoid sandstones, containing various layers of white limestone concretions, calcareous sandstones and sandy clays. The latter are often exceedingly rich in fossil plant remains, particularly *Ullmannia bronni* Copp., some araucarians and ferns, and in association with these they carry quite a high percentage of copper ore. One of these zones, called the 'Kupferlettenflötz' (copper clay measure), has a thickness of 12 to 15 in., sometimes reaching 18 in. The plant remains are for the most part completely mineralized, mostly by chalcocite; but also by native silver, pyrite, chalcopyrite, and more rarely by tetrahedrite, bornite and ruby silver. The mineralized remains of Ullmannia were called by the Frankenberg miners by the general name of 'Graupen,' and

[1] G. Würtenberger: 'Ueber die Zechsteinformation, deren Erzführung und den unteren Buntsandstein bei Frankenberg in Kurhessen,' *N. Jahrb.* f. Min., 1867, part I, pp. 10-38. A. Leimbach: 'Die permische Formation bei Frankenberg.' Marburger Dissert., 1869. E. Holzapfel: 'Die Zechsteinformation am Ostrande des Rheinisch Westf. Schiefergeb,' same, 1879. A. Denckmann: 'Die Frankenberger Permbildungen,' *Jahrb.* d. k. preuss. geol. Landesansto, 1891, p. 234 *et seq.*

went into the collections under the designations of 'Stangengraupen,' ears of corn, and 'Sterngraupen,' wings of flies, according to their forms and general appearance.

The ore is very irregularly distributed, occurring mostly in bunches. The average noted during a period of several years was 0.572 copper and 0.0013% silver.

Finally, the younger conglomerates are formed of well worn material, and are distinguished by the great amount of carbonates in their cement.

The series of sediments just mentioned lie more or less horizontally on the edges of steeply upturned strata of Devonian and Culm age. The different beds frequently overlap others of the same series. These copper-bearing beds are influenced by structural disturbances, which here have the same influence on the copper content of the sediments as the 'ridge' fissures (Rücken) of the Mansfeld area.

A different state of affairs obtains in the copper-bearing Permian at Bieber, at the northeast edge of the Spessart[1].

At that place a thinly stratified bituminous marl shale, 30 cm. (1 ft.) to 1.5 m. (5 ft.) thick, but very poor in copper, was worked for a long time, and was so soft that it could be mined with a pick. The ore contains tetrahedrite, chalcopyrite, galena and pyrite, and also carries cobalt ores near cobalt-bearing veins. This ore occurs in numerous small fissures which traverse the rock in all directions and at all angles, the most common being vertical. However, the ore is in many cases not limited to the Permian marl, but is also found in the underlying mica schist, where the latter is traversed by mineral veins. Similarly, on the border of the Rhenish Schiefergebirge, at Stadtberge in Westphalia, the copper ore, near vein fissures cutting through the bed, is to be found not only in the Kupferschieferflotz (copper shale) alone, but also in all the upper strata of the zechstein (Permian limestone), which there is 10-12 m. thick[2]; ore is also found in the Paleozoic graywackes and silicious schist beneath the ore-bearing bed proper.

Brief mention must also be made of an occurrence in the reverse direction, near Hasel and Conradswaldau in Lower Silesia, where five copper shale measures, lying close together, but carrying very little copper (1.5% on the average) occur intercalated in the dolomitic Zechstein limestone[3].

[1] Schmidt: 'Mineralogische Beschreibung des Biebergrundes.' *N. Jahrb.* f. M., 1808, p. 45. H. Bücking: 'Der nordwestliche Spessart.' Berlin, 1892, p. 133.

[2] E. Holzapfel: 'Zechstein am O.-Rande des Rhein.-Westf. Schiefergebirges.' Görlitz, 1879.

[3] Festenberg-Packisch: 'Met. Bergbau Niederschlesiens.' Vienna, 1881,

1. *The Origin of the Copper Shale and Similar Formations.*

The 'Kupferschiefer' has for a long time been regarded as a typical example of an ore deposit formed by chemical precipitation of ores (from metallic solutions) during the formation of the rock by ordinary mechanical sedimentation in a large, enclosed marine basin, and under the influence of reducing organic substances. The waters were thought to have held metallic sulphates, accompanied by alkaline sulphates, such as are found in all sea water. The alkaline sulphates were supposedly first of all decomposed by decaying organic remains, with the development of hydrogen sulphide, and the latter then precipitated the metals from the solution as sulphides. Until the last few years[1], scientific opinion adhered to the old idea first made current by J. C. Freiesleben, viz.: that the fishes inhabiting the Permian seas, the Palæonisci and Platysomas, were poisoned by the solutions carried into those waters. The bodies of the fishes often found curled up as in convulsions and distinctly preserved in the fossil impressions, were supposed to prove this manner of death. The fish remains thus accumulated, together with the finely divided bitumen, were said to have been the principal reducing agents.

One part of this hypothesis, namely, the idea that the precipitation of the particles of ore in the copper shale was from aqueous solutions and was accomplished by a reduction due to bitumen, fish remains and other organic substances, may be supposed to be generally admitted. But the effective criticisms of F. Posepny[2], H. Louis[3] and other recent authors render it very doubtful, at any rate, whether the metallic minerals were segregated *simultaneously* with the deposition of the calcareous mud. At the present time, the weight of evidence seems even to prove the other possibility; that the marly shale was impregnated *after* its deposition, by metallic solutions rising through fissures. This may be shown by a brief discussion.

It is admitted that the ocean water of the present day contains small quantities of copper compounds. According to Dieulafait[4], the mother liquors of the salt flats (basins) of the Mediterranean contain so much copper that it can be demonstrated in as little as 5 cubic cm. of the liquid. One cubic m. of sea water would contain 0.01 gram of copper. According to Dieulafait, the black, sulphur-charged matter deposited in basins in which sea water is confined always contains copper. But how

[1] R. Brauns: 'Chemische Mineralogie,' 1896, p. 387.
[2] F. Posepny: 'Ueber die Genesis der Erzlagerstätten,' 1893, p. 168.
[3] Phillips and Louis: 'Ore Deposits,' 1896, p. 54.
[4] L. Dieulafait: 'Revue universelle des mines,' 1880, Vol. VII, p. 425.

are we to imagine that these minute quantities are to be concentrated in the mud settling mechanically in the sea, so as to form such percentages as we find in the copper schist? The hypothesis of the poisoning of the fishes is, in Posepny's opinion, very improbable, for the main argument, the "convulsive curvature," is characteristic of many fish impressions in sediments free from metals, such as the Solenhofen lithographic slate and the Tertiary shales of Monte Bolca. Moreover, even the marly slate of the English Permian limestone formation, quite similar to the 'Kupferschiefer' in other respects, but carrying no copper ores, contains the same curled-up Palæonisci. Evidently the curling up is a phenomenon accompanying the rigor mortis, such as may be observed after death in many fishes of the present time, when there has been no poisoning by metals. If the theory of fish poisoning by strongly metalliferous mineral water entering the sea is maintained, how often must this rare natural event have taken place to explain the formation of the entire thickness of the copper schist! For we know that this kind of fine sediment grows very slowly.

Again we have seen that the copper is to be found at *wholly different levels* of the Zechstein, in fact, that the *copper-bearing deposits of this formation cannot possibly be grouped as a stratigraphic unit.* Yet it was precisely the constancy of level that constituted, in A. von Groddeck's[1] view, the main argument for the theory of sedimentation.

It would seem that stress should rather be laid on the other observation: that, *wherever the formations comprehended under the name 'Kupferschiefer' are ore-bearing, the Zechstein and its underlying rocks are found to be traversed by numerous fissures, which have in part the character of mineral veins. The generally recognized fact that, with few exceptions, the amount of copper in the shale increases on approaching these fissures and dislocations, is direct evidence in favor of impregnation from the fissures,* particularly since it is found that the infiltration with copper compounds has affected not only the overlying and underlying beds, but extends as far down as the mica schist.

At any rate we are not yet justified in regarding the sedimentation theory as proved beyond question, as was done until recently. We prefer instead to await further scientific investigation before definitely adopting any one theory. The author had written the above passage in this form and had delivered it for several years in lectures, when F. Beyschlag[2] published similar conclusions, thus giving a new and effective support to these deductions.

[1] A. v. Groddeck: 'Lagerstätten der Erze,' 1879, p. 301.

[2] 'Beitrag zur Genesis des Kupferschiefers.' *Zeit. f. Prak. Geol.*, 1900, p. 115.

2. *Copper Ores of the Permian Red Beds (Rothliegende) of Northeastern Bohemia.*

At various points in northeastern Bohemia[1], at entirely different geologic horizons, the Rothliegende formation contains beds impregnated with copper ores, which here and there occur in paying quantities. The best known localities are Strabaoov and Kosinetz near Starkenbach, Oberkalna, Eipel, Wernersdorf near Radowenz, Böhmisch Brod and Schwarzkostelez. At Wernersdorf the ores are found in two horizons, in a clay slate above and another clay slate below a thick bed of conglomerate. Below the zone of weathering, the ores consist of finely divided copper glance. Concretions also occur that are often as large as the palm of the hand, containing copper glance inside, which gradually passes over into pyrite. Such kidneys contain as much as 14% of copper. From the vicinity of Radowenz, calamites have been obtained, consisting of a mixture of anthracite and copper glance. Their striped surfaces bear a thin coating of malachite, azurite and clay. These oxidic ores are to be noted in fissures within these calamites, whose total copper content amounts to 32 to 50%. As late as 1891, Bohemia produced 2,400 tons of copper ore.

Similar deposits have been found in the country about Jauer in Silesia.

3. *The Copper Deposits in the Permian Formation of Russia.*

According to Nikitin[2] and other Russian geologists, the Permian formation whose nearly horizontal beds cover a vast area west of the southern Ural is divided as follows:

4. Red sandstone, variegated marls and clays of the Tartar stage, which represent a transition to the Triassic.

3. A group of strata consisting essentially of limestones, corresponding to the Zechstein of western Europe (with *Leda speluncaria, Turbonilla altenburgensis, Macrodon kingianum*, etc.).

2. Sandstones, limestone, marl and clay shales, with intervening copper-bearing beds (with *Spirifer rugulatus, Productus cancrini, Strophalosia horrescens*, etc.).

[1] O. Polak: 'Geogn. Bericht über die im Bunzlauer, Jitschiner und Königsgrätzer Kreise unternommenen Schürfungen.' *Jahrb.* d. k. k. geol. Reichsanst., 1858, p. 239. C. A. Hering: 'Die Kupfererzlagerstätte der Dyas im norsdöstl. Böhmen in Bez. auf ihre Abbauwürdigkeit.' *Oesterr. Z.* f. B. u. H., 1888, pp. 676–678. F. X. M. Zippe: *Sitzb.* Ak. d. Wiss., Vol. XXVIII, p. 192 *et seq.* G. Gürich: 'Die Kupfererzlagerstätten von Wernersdorf bei Radowenz in Böhmen.' *Zeit. f. Prak. Geol.*, 1893, p. 370 *et seq.*

[2] S. Nikitin: 'Recherches géolog. le long de la ligne du chemin de fer de Samara.' *Bull.* du Com. Géol. St. Pétersburg, 1886, Vol. V; 1887, Vol. VI, p. 225. Tschernyschew: 'Une excursion dans le gouv. Oufa et de Viatka.' Same, 1887, Vol. VI, p. 7; 1888, Vol. VII, p. 81.

1. Clayey limestones, marl and gypsums of the lowest horizon.

This shows that the copper-bearing strata occupy about the same stratigraphic position as the 'Kupferschiefer' of Germany. The Permian of the Ural contains similar copper deposits, especially in the districts of Perm and Ekaterinburg, as well as farther south in the districts of Ufa and Orenburg. It has been found that in these regions the richness of the ore decreases as one recedes from the Ural, ceasing entirely at a distance of about 500 km. (300 miles). Furthermore, it is stated that while the copper is especially concentrated around the impressions and carbonaceous remains of calamites, it also occurs in fine dustlike particles, in nodules and tufts and in small fissures. The sandstones in particular carry the ore. The ore consists chiefly of malachite, azurite, earthy red oxide of copper, and brick ore (ziegelers), as well as of copper glance, especially in the fossil remains of plant stalks. More rarely bornite, cuprite, volborthite (a basic copper vanadinate), gypsum and calcspar make their appearance[1].

The distribution of the ore is exceedingly irregular, and is limited to beds 6-70 cm. (0.2 ft.-2.3 ft.) thick, 2 to 4 of which may occur one above the other. The copper averages about 3%. The most important works are situated in the steppe of Kargalinsk, 40 km. (24 miles) from Orenburg.

The Permain formation in the Donetz area, east of Bachmut[2], also contains such deposits, which, though very poor, were worked as early as the Stone Age. They consist of grayish white sandstones, impregnated with copper ores, which are overlain by red clays and sandstones forming the base of the Permian.

4. *Copper Ores in the Permian of Texas and Nova Scotia.*

According to E. J. Schmitz[3], the Permian formation in the Red River and Brazos River districts of Texas consists of slightly inclined or horizontal strata of sandstone, clay slate, marl and conglomerate, certain beds of marl and clay slate being impregnated with copper ore, at widely different horizons and at numerous points scattered over a rather extensive area. The ores are mainly green and blue silicates and oxides. They are found especially in the form of fossil wood, in log-shaped pieces, with a

[1] E. Neubert: 'Die Kupfererzlager der Kargalinskischen Steppe.' *Berg u. Hütten Zeit.*, 1863, pp. 141, 169. C. R. Förster: 'Notizen über den Kupferbergbau der Karkalinskischen Steppe.' *Idem*, pp. 193–195.

[2] A. Reh: 'Das Kupfererz- und Salzvorkommen in der Permischen Formation Südrusslands.' *Z. f. B. H. u. S. in Preussen*, 1881, Vol. XXIX, p. 276.

[3] E. J. Schmitz: 'Copper Ores in the Permian of Texas.' *Trans. Am. Inst. Min. Eng.*, 1897, Vol. XXVI, pp. 97–108.

diameter of several centimeters, but also as finely interspersed particles and as rounded concretions. The mineralized logs and the concretions contain 20-60% copper, the entire masses enclosing them carrying for the most part but 3.5-5%, the finely impregnated strata as a rule much less.

Closely analogous deposits have been described by H. Louis[1] from the Permian of New Annan on French river in Nova Scotia, the chief difference being that the copper ores there consist mainly of copper glance, more rarely of copper pyrite, indigo copper, etc.

5. *The Copper Deposits of Corocoro in Bolivia.*

Corocoro lies in the Serrania de Corocoro-Charcarillo, which rises, island-like, from the high plateau of Bolivia south of Lake Titicaca[2]. The high plateau itself extends from the Andes on the west, which are formed of Jurassic strata with numerous eruptive stocks of Tertiary age, to the Cordillera Real on the East. The latter range consists of Paleozoic schists with numerous trachyte and porphyry dikes. The plateau is entirely covered with Pleistocene sands, clays and drift. Only in the neighboring mountains do the Permian bed rocks crop out. The Permian formations consist of clays, argillaceous shales and breccia-like conglomerates and sandstones, cemented by calcareous material rich in iron. The strata are almost all red. The clays and shales also contain layers and strings of gypsum and a little rock salt.

The mountain village of Corocoro is situated in a deep-cut valley on the west side of the Serrania. The copper-bearing measures worked in the neighborhood of the town belong to the Permian formation just described. They consist of ash-gray, fine-grained to coarse-grained sandstones and fine sandstone conglomerates, stained by patches and disseminated grains of blue, gray, green and black ore. According to H. Reck[3], whom we follow, the measures have an average thickness of 0.5-2 m., and carry native copper in grains, in massive plates up to one foot in thickness, and in masses with the form of hair, wire, moss, shrubs, branches, leaves and fine crystals; also in pseudomorphs after aragonite crystals. The principal bed, Buen Pastor, does indeed grow to be as much as 12 m. thick, but its brown-red rock is in the main devoid of ore, only the gray or green spots in it containing ore in paying amount. In the lower parts, this bed also contains native copper and some native silver, while the upper portions

[1] H. Louis: Discussion of the paper by Schmitz, *op. cit.*, p. 1051.

[2] David Forbes: 'Geology of Boliva and Southern Peru.' Quarterly Jour. Geol. Soc., London, Vol. XVII, 1861, p. 41.

[3] H. Reck: 'Das Vorkommen u. s. w. des Kupfers in der Serrania de Corocoro-Chacarilla.' *Berg u. Hütten. Zeit.*, 1864, pp. 93–96.

contain malachite, red copper ore, copper arsenide, azurite, etc. The ores are always accompanied by gypsum. The large, wavy copper plates, called *charque* (air-dried meat), are sometimes entirely enveloped in gypsum. Mention must be made of the occurrence of bones, whose marrow cavities are filled with native copper, and of mineralized wood remains. The strata are traversed by fault fissures.

Copper was mined on the Bolivian plateau as early as the time of the Incas. Modern mining dates only from 1832, the town of Corocoro being founded in that year. In the nineties the average yearly production of the copper mines of the Corocoro district was 2,300 tons of copper. In the sixties, on the contrary, the average annual exportation from the district was 3,000-3,500 tons copper and 25 tons silver.

6. *Copper Ores in the Bunter (Triassic) Sandstone Formation of Saint Avold and Wallerfangen.*

In the district of St. Avold and Wallerfangen near Saarlouis in Lorraine, the Bunter sandstone formation is divided as follows:

Upper Bunter sandstone or Voltzia sandstone.	7. Shelly limestone, with gypsum in its lowest part.
	6. Red clays and sandstones of the Rothliegende.
	5. Fine-grained sandstone, the so-called stone-breakers' bed, with intercalated clays and plant remains; in places with copper ores, about 12 m.
	4. Drusy, iron-charged sandstone with dolomite lenses, 6 m.
	3. Red clay layer with dolomite lumps, a few centimeters.
	2. Conglomeratic sandstone, here and there with copper ore, up to 9 m.
	1. Principal variegated sandstone or Vosges sandstone, more than 300 m.

The ore is restricted to that portion of the sandstone beds immediately overlying and underlying the two dolomite-bearing beds. Where ore exists at all, it impregnates layers only 6-60 cm. thick[1].

It consists of an impregnation with malachite and earthy azurite, and in the lower horizon also with earthy black oxide of copper. At certain points the copper ores are replaced by lead ores, galena and lead oxide. The ore minerals occur as minute grains or films, dusted over the surfaces of small fractures, and as nodules sometimes as large as a walnut, and are often found replacing the woody parts of fossil plants.

The ore-bearing rocks are restricted to certain zones, separated by barren rock. These zones, as a rule, run parallel to the strike, and seem to be connected, especially at Saint Avold, with the anticlines of the Bunter

[1] Jacquot: 'Notice historique et géologique sur les mines de St. Avold,' etc. *Ann. de l'ac. de Metz*, 1857. C. Simon: 'Kupfer- und Bleierzablagerungen im bunten Sandstein, etc., von Saarlouis und St. Avold.' *Berg u. Hütten. Zeit.*, 1866, pp. 412, 421, 430. Hauchecorne: 'Ueber Bleierze aus dem Bunstsandstein von Saint-Avold.' *Z. d. D. G. G.*, 1879, Vol. XXXI, p. 209.

Sandstone strata, for they here coincide with the side of an anticline dipping west and southwest. But even within these zones the horizons mentioned above are impregnated with ore only where one of the numerous north-south fissures cuts through the zones.

This appears from the ground plan and section given in Fig. 209. Such fissures were disclosed, for example, a half century ago in the Barbara mine near Wallerfangen. According to C. Simon, they formed open clefts, often an inch across and mostly dry, whose sides were ornamented with magnificent green and blue stars of concentric-radiating crystals of malachite and azurite. Sometimes the fissures were closed and not infrequently filled entirely with compact azurite and malachite. In fact, the entire area of Bunter Sandstone is strongly fissured. Some fissures cause considerable dislocations, for example, the one which runs from west-eastward from Quatre Vents, south of Longeville, across the Kreutzberg, toward the Heiligenborn, near Saint Avold. In the immediate vicin-

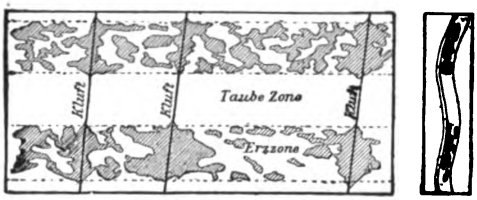


Fig. 209.—Ground plan (a) and elevation (b) of the ore deposit of Wallerfangen and Saint Avold, showing the arrangement of the ore zones and fissures (kluft). Taube zone = barren zone; Erz-zone = ore-bearing zone. (C. Simon.)

ity of this fissure, which throws the Muschelkalk down to the level of the Bunter Sandstone, we find in the former the lead deposits of the Castelberg near Longeville, the copper ores in the Hochwald, the rich calcareous lead-bearing rocks in the Bleiberg near Saint Avold, and finally the copper ores of Helleringen. The Heiligenborn, a chalybeate sour spring, issues from this same fault line. It seems also that this line of earth movement continues across Cocheren to beyond the Schlossberg near Forbach. It would thus take in the warm saline spring of Cocheren.

In the Hochwald another fissure, striking north-south, is noteworthy. It dips east at an angle of 70° and the copper ore bed shows a vertical displacement of 2 m. The fissure is 4.5 m. wide, and is filled with copper ore, barite and red silicious iron ore. However, the ore is limited to the ore zone at that place, and to the level of the ore-bearing bed.

The genesis of these ore deposits is ascribed by C. Simon to a precipitation simultaneous with sedimentation, although the conditions described by him in detail, and just summarized, seem to indicate ore deposition by subsequent infiltration of ore solutions as more probable.

The copper mining operations of Wallerfangen may be traced back to Roman times. From 1500 on, azurite in particular was exported to Italy for painters' colors. Subsequently the mining operations ceased, but were resumed in the fifties.

Triassic sandstone impregnated with copper ore is also known to occur at Twiste[1] near Arolsen, where there are four beds with copper glance and malachite; also at Bulach[2] in the Black Forest of Wurtemberg (where it is associated with gray copper ore), and at Büdingen[3] in the Grand Duchy of Hesse.

7. *Copper-bearing Triassic Sandstones in New Mexico.*

In the Nacimiento mountains, which extend with a north-south course through the northwest part of New Mexico west of the headwaters of the Rio Grande del Norte, the mountain core consists of granite. This is overlain by essentially calcareous strata of Carboniferous age, followed by white and red Triassic sandstones, marls and gypsums in steeply upturned beds overlain by Cretaceous strata[4].

The Triassic sandstones and conglomerates, whose age is shown by cycad remains, especially *Podozamites crassifolia,* contain certain beds rich in copper ores. The copper occurs in intimate connection with the numerous leaves, stalks and stems of the plant remains mentioned. The ores are principally bornite, copper glance and melaconite (black oxide of copper). They appear interspersed throughout the entire thickness of the sandstone deposit, which is 20-30 m. (65 ft.-98 ft.) thick, but are found concentrated only in scattered patches in the joints between the strata, as well as in whole beds of the above mentioned plant remains. The ores also contain a very small amount of silver.

8. *Copper-bearing Sandstones of the Copper Basin, Arizona.*

A deposit closely resembling that just noted, but without the plant remains, occurs at Copper Basin, Yavapai county, Arizona. A coarse-grained granite, traversed by porphyrite dikes and a great quartz vein,

[1] B. v. Cotta: 'Erzlagerstätten,' Vol. II, pp. 165, 211.

[2] Quenstedt: 'Epochen der Natur,' p. 469.

[3] C. Simon: 'A. a. O.', p. 412.

[4] J. S. Newberry: *Rep.* of Exploring Exped. in 1859. Washington, 1876. F. M. F. Cazin: 'New Mexico and Lake Superior as Copper Producers,' *The Engineering and Mining Journal,* 1880, p. 87. *Ibid.*, 'Genesis of Ore Deposits,' 1902, pp. 210, 251.

is covered by conglomerates, breccias and sandstones, of uncertain age, in part dissected into isolated blocks. These beds contain azurite and malachite in the cementing material and also as incrustations around the grains and pebbles of the sandstones and conglomerates. The percentage of copper is stated to be 12-15% throughout beds 1 to 3 m. thick. The underlying granite also carries some copper ore, in its uppermost part, as veinlets and impregnations of malachite and cuprite, while at great depths copper pyrite occurs associated with quartz. It thus seems certain, as W. P. Blake[1] pointed out, that the sandstones received their metal contents found below subsequent to their deposition.

9. *Copper Ores in the Cretaceous of Angola.*

Conglomerates strongly impregnated with copper ores have recently been found at Senze do Itombe, in the Portuguese colony of Angola, West Africa. According to F. W. Voit's[2] investigations they are intercalated in the Cretaceous limestones and various sandstones, which have a dip of 12° southwest, resting against crystalline schists of the higher ground inland. The beds above and below the conglomerates consist principally of magnificently crystallized malachite, and azurite, accompanied, according to Voit, by volborthite, chrysocolla, calcite, aragonite, and barite. These ores are partly replaced in depth by copper glance accompanied by a little galena. It is probable that this rich deposit will be worked very soon, as it is situated near the railway and only 20 kilometers from the navigable Cuanza river.

10. *The Bedded Copper Deposits of Boleo, Lower California, Mexico.*

Boleo lies on the east side of the Peninsula of Lower California, opposite the Port of Guaymas on the Sonoran coast. According to E. Fuchs[3], the region is part of an extensive plateau, built up of well bedded trachytic and andesitic tuffs and conglomerates, of Miocene age, the strata being gently inclined towards the sea. An isolated dome rises above this tract. The plateau is scored by four deep gorges. The entire series of tuff beds is partly covered by a vast basalt sheet. On the west the plateau abuts against a trachytic mountain range running along the coast (Fig. 210).

[1] W. P. Blake: 'The Copper Deposits of Copper Basin, Arizona, and their Origin.' *Trans.* Am. Inst. Min. Eng., 1889, Vol. XVII, pp. 479–485.

[2] F. W. Voit: 'Die Kupfererzvorkommen bei Senze do Itombe,' etc., *Zeit. f. Prak. Geol.*, 1902, pp. 353–357.

[3] E. Fuchs: 'Notes sur les gisements de cuivre du Boleo.' Assoc. Franc. pour l'avancem. des sc., 1885. Fuchs and De Launay: 'Traité,' etc., 1893, p. 349. P. Krusch: 'Kupfererzlagerstätten in Nieder Calif.,' *Zeit. f. Prak. Geol.*, 1899, p. 86.

The copper ore is found in three separate beds, the lowest 0.6-3 m. thick, the middle 0.8-2.3 m., the upper on an average 1 m. The beds are largely composed of a clayey tuff of grayish lilac color, containing 0.1-6% salt (NaCl). The ore is scattered through this clay in the form of granules, small fragments, or rounded concretions, which at the base of the bed are always concentrated into a compact layer 15 to 20 cm. (6 to 8 in.) thick. The ore consists of cuprite, with some atacamite, azurite, malachite, chrysocolla and crednerite ($Cu_3Mn_4O_9$). Owing to the rather abundant admixture of crednerite, the analysis of the ore shows besides 15-26% copper and 4-12% Fe_2O_3, a large amount (7-24%) of manganese (P. Krusch).

The middle bed, which is especially rich in silica in the neighborhood of a transverse fault, probably as a result of impregnation by hot spring waters, is remarkable for its abundant oolitic concretions of oxidic and carbonatic copper ore, called *boleos*. These concretions contain 25-40%

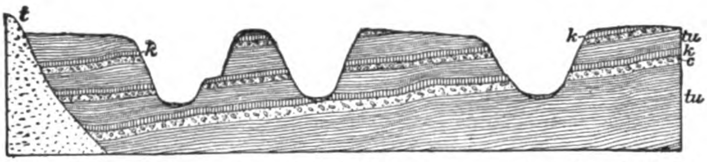


Fig. 210.—Diagrammatic section through the copper deposits of Boleo, Lower California, Mexico. (Fuchs.)
t, trachyte; tu, clayey tuffs; c, conglomerates; k, copper beds.

copper and attain a diameter of several inches. In the lowest bed, copper glance and covellite occur[1].

The deposits began to be worked in 1884. The production was:

1898: copper 9,857 tons, ore 192,000 tons.
1902: copper 10,956 tons, ore 275,635 tons, averaging 3.95% Cu.

(c) Lead Deposits.

1. *The Nodular Ores of Commern in the Rhine Province.*

The lead ores of this district are found in sandstone beds that form part of the Triassic series known as the Bunter sandstone. This formation lies above the strongly folded and upturned Devonian (Rhenish schist), near Commern, between Aachen and Bonn, to the north of the Eifel mountains. The sandstone strata extend over a length of about 3 miles and a breadth of one mile, and are in part overlain, conformably by the Roth and Muschelkalk. The lead ores occur in the lower beds of the so-called Haupt-

[1] *The Engineering and Mining Journal*, 1903, Vol. LXXVI, pp. 366, 765.

buntsandstein, constituting the lower division of this Bunter formation. The Knottenflötze (nodular ore measures) of the Bleiberg belong to the Meinertzhagener Bergwerksactiongesellschaft and some neighboring mining

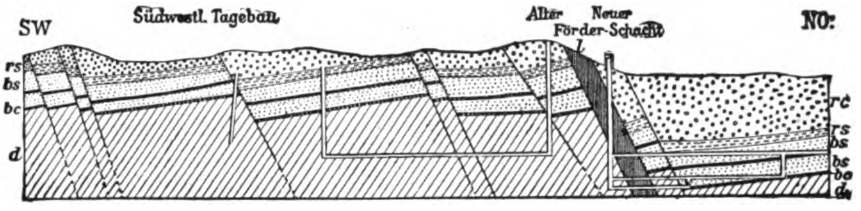


Fig. 211.—General section through the lead ore deposits of Griesberg, near Commern. (Blanckenhorn.)

rc, red conglomerates; rs, red sandstones; both overlying (upper Hauptbuntsandstein); bc, conglomeratic horizons of the lower Hauptbuntsandstein (Wackendeckel); bs, lead-ore bearing, bleached sandstones (nodular measures); d, Devonian graywackes; l, clayey and sandy fillings of a fissure of displacement.

grants. These deposits are worked, between Call and Mechernich, over an area one mile long and ¼ mile wide[1].

In the region of the Bleiberg, the sandstone strata dip northwest at 5 to 12°, but the beds are broken and greatly disturbed by innumerable faults. In

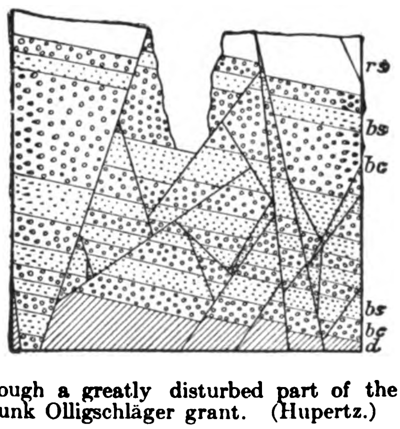


Fig. 212.—Section through a greatly disturbed part of the lead deposits of the Schunk Olligschläger grant. (Hupertz.)

many places the nodular measures are literally chopped up by these faults. The two sections, Fig. 211 and 212, exhibit the structure of a less disturbed and of an unusually disturbed part respectively.

[1] C. v. Oeynhausen and H. v. Dechen: 'Der Bleiberg bei Commern.' *Karstens Archiv*, 1825, Vol. IX, pp. 29–40. C. Diesterweg: 'Beschreibung der Bleierzlagerstätten, des Bergbaus und der Aufbereitung am Bleiberge bei Commern.' *Z. f. B.-, H.- u. S.-W.* im preuss. St., 1866, pp. 159–196. M. Blanckenhorn: 'Die Trias am Nordrande der Eifel.' *Abh.* zur geol. Spezialk. von Preussen, 1885, Vol. VI, p. 2. F. W. Hupertz: 'Der Bergbau, etc., des Mechernicher Bergwerks-Aktien-Vereins.' Köln, 1886.

The two most important displacements are the Griesbacher fault, which, with its accompanying parallel side fractures, displaces the measures in step faults for 42-46 m. (138-151 ft.) and the Sonnenberger fault, which is filled with barite and shows splendid slickensides. The latter fissure, according to M. Blanckenhorn, may have a throw of 140 m. (460 ft.) It forms the boundary of the Bleiberg proper at the South.

The Bunter formation of this region contains, especially in the lower horizon, many intercalated conglomeratic beds (called Wackendeckel). The pebbles of the rock consist of quartzite, graywacke, sandstone and quartz. These conglomerates vary greatly, both in their relative position and in their thickness, so that no section can be given that will apply to all the mines.

At Mechernich the following series of beds occur over a considerable distance:

Drift sheet Red sandstone Conglomerate Yellow sandstone Conglomerate Clay	These upper beds attain a maximum thickness of 50 m (164 feet).

Upper nodular layer, 26 m.
Conglomerate.
Lower nodular layer (18 m.), but often with 3 to 4 congl. layers.
Bottom conglomerate, 0.5 to 6 m.
Red clay with fragments of greywacke.
Devonian country rock (lower Devonian).

At Griesberg, near Commern, the following section occurs (according to M. Blanckenhorn):

Cover of drift and soil.	
Conglomerate with red sandstone intercalations (upper Hauptbuntsandstein, devoid of ore)	3 m
First nodular measures in the upper third reddish-yellow sandstone devoid of ore, with merely barren nodules, in the lower part *white* and carrying ore	9.0–11 m
Conglomerate (Wackendeckel)	0.6– 2 m
Second nodular measure, with lead ore nodules, in places also with oxidic copper ores	10 m
Basal conglomerates, in places with galena and malachite	2.0– 4 m
Devonian formations.	

The nodular measures consist of a whitish, mostly readily friable sandstone, composed of quartz grains of the size of a millet seed, held in a clayey or slightly calcareous cement. The nodules (Knotten) of lead ore occur scattered, close-crowded or united into rounded concretions, 1 to 3 mm. in diameter, formed of sand and galena, more rarely also of cerussite, or, at the Griesberg, of oxidized copper ores. Through the crystallization force of the galena, they have at times assumed hexahedric outlines, or well formed cubes may project from them. Wherever these ore nodules occur, the surrounding sandstone is whitish through bleaching. Organic material no doubt effected not only this reduction of the ferric oxide, which elsewhere colors the sandstone, to ferrous oxide, but also induced the segregations of the lead sulphide from solution.

Besides the nodules of lead ore, barren nodules also occur, concretions whose cement is merely clayey or calcareous.

According to F. W. Hupertz the material obtained by washing consists of 98 parts of coarse-grained nodules with a lead content of 20 to 24%, and of two parts of fine-grained smelting ore with 55-60% lead.

At Bleiberg, according to C. Diesterweg, in the workable portions of the ore bed the nodules form 4-10% by weight of the entire mass of the measure. The average lead content of the workable measures is 1.5-2%, and the silver content is stated at 1·to 6 grams per ton. The lead is, however, not always concentrated into nodules, but often occurs as cerussite uniformly distributed throughout the sandstone as a cement between the quartz grains. Sometimes cerussite also forms a crust, probably of secondary nature, around the galena nodules.

Nodules of lead ore and copper ore but rarely occur together. In the mining districts of Günnersdorf and New-Schunk Olligschläger, occasional patches occur which contain nodules of copper ore whose green color contrasts sharply with the rest of the mass, which is studded with blue-gray lead ore nodules. Galena is also found in the conglomerate (Wackendeckel), sometimes finely crystallized, but not in workable amount.

Somewhat different conditions prevail at the lead deposits north of the Tanzberg near Keldenich, the so-called Lehmerzlager (clay ore beds). The ore beds are brownish-red clays containing thin layers of fibrous lead carbonate (banded ore) or clayey concretions of ore (hepatic ore). As they are intercalated between the two variegated sandstone strata, they belong to a higher horizon than those mentioned above

Finally, mention must be made of the faults, which cut the sandstones and conglomerates, cutting clean through the quartz pebbles of the latter rock. These fissures contain galena and cerussite both well crystallized, together with pyromorphite, pyrite and chalcopyrite.

The origin of these stratified lead deposits has usually been ascribed to a segregation of the galena during the deposition of the sandstone.

The more probable theory advocated by Posepny[1] is that the ore was deposited secondarily in the greatly dislocated sandstone strata by uprising springs following the faults. He points out the significant fact that, while the nodules as a rule are arranged parallel to the stratification, yet close to the fault fissures which cut through the sandstone the nodules are

[1] F. Posepny: 'Genesis,' 1893, p. 173.

grouped in zones parallel to the walls of the steeply dipping fissures. The correctness of this reasoning is confirmed by the vein-like deposits of galena, in the Devonian Eifel limestone of the neighboring Tanzberg, near Keldenich, worked by the ancient Romans. Along the bedding plane between the Bunter sandstone and the Eifel limestone, the deposits just named become enlarged to regular funnels, filled with a crumbly efflorescent clayey iron ore, rich in manganese, and carrying copper and lead ores with iron pyrite.

The iron industry of the Mechernich district also dates back to Roman times. At that time, besides the lead ores in the Devonian limestone of Tanzberg, the more compact galena ores of the Wackendeckel were mined. On the other hand the exploitation of the nodular sandstone began in 1629. For many years subsequent to 1852, it was partly carried on by open cuts, but the recent work is all underground. In the seventies the production of lead was 10,000 to 15,000 tons, that of silver 2,300 to 3,700 kilograms per year. In 1900 Mechernich produced 262,126 cubic meters of nodular sandstone, which yielded 22,145 tons of ore (1 ton of ore to 11.84 cubic meters of material extracted).

Lead ore impregnations also occur in the Triassic sandstone at Saint Avold near Saarlouis, alongside of the copper ore impregnations mentioned on page 500. They are exclusively confined to the immediate vicinity of faults. According to Fuchs[1] the ores of the Bleiberg near Saint Avold also contained 560 grams of silver per ton of lead.

2. *Lead Ores of the Triassic Sandstone at Freyhung in the Oberpfalz of Bavaria.*

At Freyhung, the headwater region of the Vils, north-northeast of Amberg, and further northeast near Pressath in the Valley of the Naab, the Keuper formation found in the mountains forming the eastern border of Bavaria contains lead deposits along the Freyhung-Kirchenthumbach displacement[2]. The Keuper of that locality is divided into:

3. Rhaetic (yellowish-white sandstones and clay slates).

2. Keuper (Gyps Keuper; bright red, green and mottled marls, clay and sandstones).

1. Kohlen Keuper.

In the lower part of the Keuper formation there are intercalations of white, kaolinous sandstones with pockets and impregnations of fine-

[1] Fuchs and De Launay: 'Traité,' 1893, Vol. II, p. 658.

[2] B. v. Cotta: 'Erzlagerstätten,' Vol. II, p. 192. K. Gümbel: 'Ostbayerisches Gerenzgebirge,' p. 687. F. Posepny: 'Genesis,' 1893, p. 173. E. Kohler: 'Die Amberger Erzlagn.' Geog. *Jahrb.*, Munich, 1902.

grained galena and lead carbonates and efflorescent ore, as well as layers of clay impregnated with cerussite. The principal bed is from 1 to 3 m. thick, and consists of a white friable sandstone, containing an average of 5-10% cerussite and galena. The ore mostly occurs associated with plant remains in the Keuper sandstone, especially fragments of tree trunks. F. Posepny figured a cross-section of a mineralized trunk, which has been for the most part transformed into galena, while, in the bark, iron pyrite has been deposited.

The lead mining industry was formally productive at Freyhung, and was resumed in the eighties at the Vesuv mine by the Bavarian Lead Mining Company.

(d) Silver Deposits.

The Silver Sandstones of Utah.

In Washington County in the State of Utah, near the Arizona boundary, the prevailing Triassic formation consists of highly inclined strata of slate and sandstone. Two of the beds known as the White Reef and the Buckeye Reef consist of whitish gray or reddish brown sandstones, which contain many indeterminable plant remains, and are, according to C. M. Rolcker, and others, impregnated in many places with silver chloride and some native silver, so that the silver content amounts to 0.085%. At lower horizons, rich silver sulphide and copper ores also occur.

While J. S. Newberry considered this ore to have originated simultaneously with the sandstone, most other authors are of the opinion that the ore was introduced secondarily. C. M. Rolcker[1] bases his belief especially on the fact that the sandstone is richest near fault fissures, which, beside the clays, sometimes also contain silver ores. For that matter, in one end of the same sandstone bed rich zones are separated from one another by broad intervening streaks of barren rock.

(e) Stratified Gold Deposits of Paleozoic Formations.

1. *The Gold-bearing Conglomerates of the Witwatersrand, South Africa*[2].

Of all the stratified gold ore deposits of the globe, the conglomerate beds of the Witwatersrand, or of the Rand, as it is most commonly called, in

[1] Ch. M. Rolcker: 'The Silver Sandstone District of Utah.' *Trans.* Am. Inst. Min. Eng., 1880, Vol. IX, p. 21. R. P. Rothwell: 'The Silver Reef District, Southern Utah,' *The Engineering and Mining Journal*, Vol. XXIX, pp. 25, 48. J. S. Newberry: *Rep.* of the Stormont Silver Mining Co., *The Engineering and Mining Journal*, Vol. XXX, p. 269.

[2] The most important publications on the Rand are: E. Cohen: 'Goldführende Conglomerate in Südafrika.' *Mitth.* d. naturw. Vereins f. Neuvorpommern und Rügen. Also 'Geogn.-petrogr. Skizzen aus Südafrika II.' *N. Jahrb.* f. Min., 1887, Vol. V, p. 210. A. Schenk: 'Ueber das Vorkommen des Goldes im Transvaal.' *Zeit.* d. D. G. G., 1889, Vol. XLI, p. 573 *et seq.* W. H. Penning: 'A Contribution to the Geology

the Transvaal, are of the greatest scientific and economic importance. Accordingly they are the subject of many scientific works, from the most important of which we cull the following description:

The Witwatersrand forms the north edge of the so-called Hoogeveld, an indented line along which the undulating plateau drops steeply down to the much lower hilly country about the capital, Pretoria. The lowest part of this scarp is formed of granite and crystalline schists, the upper of clay slates and quartzites of the Barberton series, the two together representing the South African Primary formation. On these rocks is superimposed, probably uncomformably near the edge of the plateau, the Witwatersrand formation, whose age has not yet been determined with perfect certainty, though G. A. F. Molengraaff regards it provisionally as part of the Primary formation. This is in turn overlain, as has been recently demonstrated, by the overlapping Devonian 'Cape formation.' The latter is divided, from below upwards, into the Black Reef strata (=Table Mountain sandstone), the Malmani dolomite and the slates and quartzites of the Gatsrand, also called Pretoria series or Magalies strata, in turn overlain, unconformably, by the horizontal, coal-bearing Karroo formation of upper Carboniferous to Permian age.

These relations are exhibited in the section, Fig. 213. This also shows that the top of the Witwatersrand formation is formed by a sheet of diabase amygdaloid, 400 to 700 m. thick, and that the strata are arranged in the form of a synclinal basin, whose south side has been subjected to many disturbances.

In these statements we are following the facts presented by the Geologic

of the Southern Transvaal.' *Quart. Journ.* Geol. Soc., 1891, Vol. XLVII, p. 452. W. Gibson: 'The Geology of the Gold-bearing and assoc. Rocks of the Southern Transvaal.' *Quart. Journ.* Geol. Soc., 1892, Vol. XLVIII, p. 420. F. Abraham: 'Aufrichtige Geschichte der Goldminen des Witwatersrandes.' Berlin, 1892. L. de Launay: 'Nouveaux gisements d'or du Cap.' *Bull.* Annales des mines, 1892, p. 136. G. A. F. Molengraaff: 'Beitrag zur Geologie der Umgegend der Goldfelder auf dem Hoogeveld,' etc. *N. Jahrb.* f. Min., 1894, Vol. IX. Schmeisser: 'Ueber das Vorkommen und die Gewinnung der nutzbaren Mineralien in der Südafrikanischen Republik.' Berlin, 1894. Kuntz: 'The Rand Conglomerates.' *Rep.* of Geolog. Soc. of South Africa, 1894. F. A. Hatch and J. A. Chalmers: 'The Gold Mines of the Rand.' London, 1895. L. de Launay: 'Les mines d'or du Transvaal.' Paris, 1896. Gives the best summary of the geological occurrence and a complete bibliography. *Ibid.*, *The Engineering and Mining Journal*, 1897, Vol. LXIII, pp. 631-659. K. v. Kraatz: *Zeit. f. Prak. Geol.*, 1896, p. 188. G. F. Becker: 'The Witwatersrand Bankets, with notes on other gold-bearing puddingstones.' 18th *Ann. Rep.* U. S. Geol. Survey, 1896–97, part V. *Ibid.*, *Amer. Jour. Sci.*, Mar., 1898, pp. 193-208. P. Krause: *Zeit. f. Prak. Geol.*, 1897, p. 12. G. A. F. Molengraaff: *Ann. Rep.* of the State Geologist of the S. African Rep. for 1897. Johannesburg, 1898. S. J. Truscott: 'The Witwatersrand Goldfields Banket and mining practice.' London, 1898. G. A. F. Molengraaff: 'Die Reihen folge und Correlation der geol. Form. in Südafrika.' *N. Jahrb.* f. Min., 1900, Vol. I, pp. 113–119. Also 'Géol. de la Républ. Sud-Africaine,' p. 23. L. Kessler: 'Valuation Plan of the Witwatersrand Goldfields.' London, 1902. J. H. Curle: 'Gold Mines of the World,' p. 127. T. H. Hatch and G. S. Corstorphine: 'Origin Witwatersrand Gold.' *The Engineering and Mining Journal*, Jan. 12, 1905.

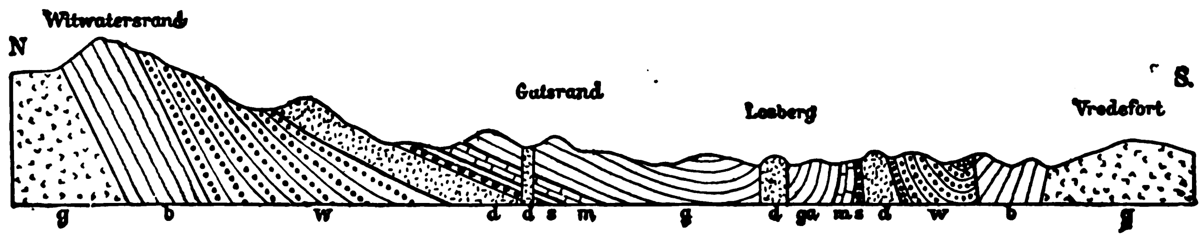


Fig. 213.—Cross-section through the Witwatersrand syncline. (Molengraaff.)

g, (ends) granite and crystalline schists; b, clay slates and quartzites of the Barberton formation; w, Witwatersrand strata with the conglomerate measures; d, diabase; s, Black measure; m, Malmani dolomite; g (center), and ga, slates and quartzites of the Gatzsrand.

Bureau at Pretoria. In contrast to this view, the Witwatersrand formation was quite recently and quite generally regarded as the lowest member of the Cape formation.

On account of their synclinal folding, the series of strata containing the gold-bearing conglomerates outcrop not only at the Rand itself, that is to say, in the vicinity of Krugersdorp, Johannesburg and Bocksburg, where their thickness is about 7,500 meters (24,600 ft.), but also farther south, in the opposite side of the syncline, at Reitzburg and near Heidelberg. The outcrop, situated far off to the southwest at Klerksdorp, belongs to the western part of the north side of the fold. The axial line of the entire syncline runs nearly in a semicircle from southwest to northeast. The north side of the syncline shows almost uniformly a very steep dip at the outcrop, which becomes more and more horizontal with increasing depth, a feature favorable for mining.

At Johannesburg, the center of the South African gold mining industry, seven groups of reefs of the gold-bearing conglomerates are known, to which must be added an eighth, the Black Reef, belonging to the Cape formation. The intervening strata consist mainly of quartzitic sandstones, more rarely also of slates. The most important is the Main reef series, embracing the North reef, Main reef, Main reef leader, Middle reef, South reef and South reef leader. It had been exploited to a distance of 80 km. (48 miles) as early as 1894.

The thickness of the reefs varies from several meters to a complete wedging out. In the Stall reef of the Du Preez mine it even attains 30 m. However, the thinner reefs are the richer.

Petrographically the conglomerates, there usually called banket reefs (banket, a baker's roll), consist of pebbles of quartz and quartzite, rarely also of silicious schist, held together by a cement of small quartz granules and iron pyrite with associated gold particles. The pebbles, mostly of the size of a hazel nut up to a hen's egg, rarely measuring 10 cm. or more, are often deformed, flattened, wonderfully distorted or splintered, evidently through secondary action. Strong pressure effects are also often shown in the cement by the splintered form of the quartz granules. The rounded pyrite granules that are occasionally found have a rolled appearance, but seem to be merely individuals whose shape is due to pressure.

The iron pyrite occurs in rather irregular distribution, as may be gathered from the photographic reproduction of a thin section, Fig. 214. Its granules often form a fairly continuous crust around the pebbles. Sometimes it is also concentrated in delicate films, running parallel to the stratification.

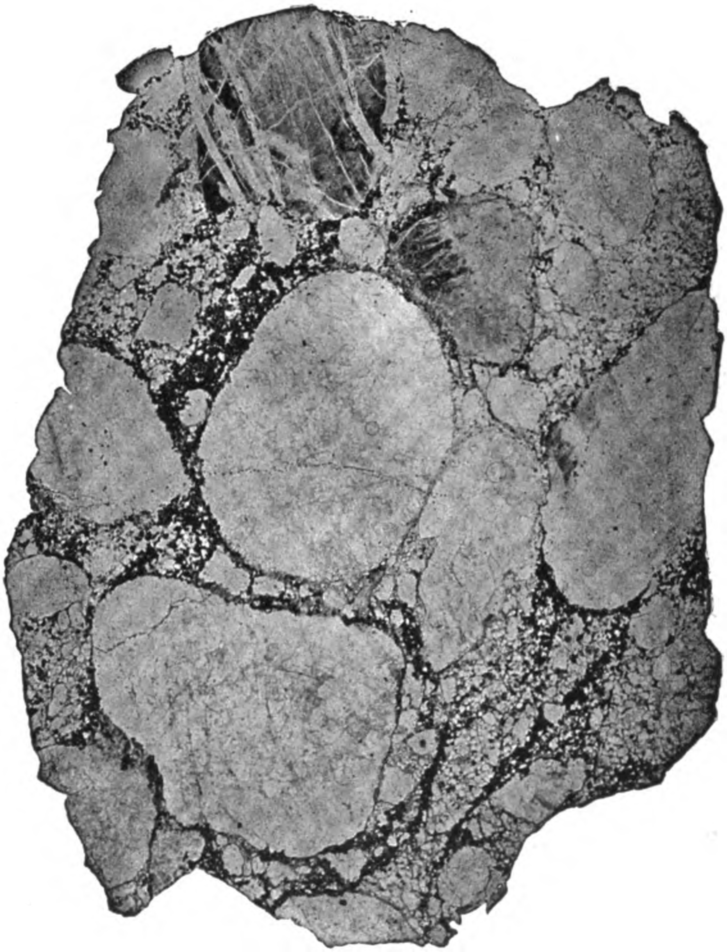


Fig. 214.—A piece of conglomerate from the main reef leader of the Crown Reef Gold Mining Company.

Photograph of thin section with transmitted light. (This section shows the distribution of the dark iron pyrite intergrown with gold. Enlargement 5—4.)

The gold is never found in smooth granules or flakes, as in the case of alluvial gold, but in microscopic crystals and in jagged crystalline aggregations, which often send out minute stringer-like appendages. It is mainly, perhaps exclusively, associated with zones of pressure and shearing, and is found, together with secondarily formed quartz, in the midst of a mosaic of crushed quartz fragments. The gold aggregations are mostly intimately intergrown with pyrite in such a way that the gold often encrusts a core of pyrite, or several pyrite fragments are cemented by gold. The gold is always found in the cement. In the rare cases in which it is found inside of pebbles its primary character seems very doubtful. They may represent cases in which the gold immigrated along secondary planes of fracturing. On the other hand, non-auriferous pyrite is known with certainty to occur inside the pebbles. In the cement the pyrite may occupy 3 to 5% of the total mass.

Besides pyrite and gold, this cement occasionally carries other ores, though in very small amount, namely copper pyrite, galena, zinc-blende and stibnite. Among non-metallic ingredients chlorite and a green hornblende in minute prisms are often quite abundant, also a green mica, talc, rutile and corundum.

A strange occurrence, reported by Gardner F. Williams[1], was the presence, in the stamp mill troughs that served for dressing the auriferous conglomerates of the Klerksdorp mines, of some green diamonds.

The average gold content of all the reefs of the Rand worked in 1892-3 was, according to Schmeisser, 23 grams per ton, not counting the loss in dressing; in his opinion the real content is 28-30 grams per ton. The coarser the pebbles, the richer is wont to be their cement.

Information upon the intimate connection of the gold with the pyrite may also be gleaned from the results obtained in milling the ore. According to Krause only about 64% of the gold is obtained from the amalgamation plates, another 18% through the cyanide process, while 18% remains in the tailings. This very fact points to an intimate coalescence of the gold with the pyrite, such as we found by means of the microscope. As a rule the gold is perceptible to the naked eye only in the red oxidized uppermost parts of the reefs, where the pyrite has been decomposed into red and brown hematite. At 30-40 m. (98-131 ft.) vertical depth the sulphides begin to make their appearance. Moreover, from 40 m. (131 ft.) downward, the hardness of the conglomerates increases more and more until at about 60 m. (196 ft.) primary, very firm "blue rock" becomes predominant.

The distribution of the gold in the several reefs is by no means uni-

[1] Gardner F. Williams: 'The Diamond Mines of South Africa.' New York, 1902, p. 523.

form, as appears from the following table taken from the work of L. de Launay:

VARIATION OF THE AVERAGE GOLD CONTENT AT DIFFERENT LEVELS IN THE FERREIRA MINE.

South Reef.			Main Reef Leader.		
Level.	Average thickness in cm.	Average content in gm. per ton.	Level.	Average thickness in cm.	Average content in gm. per ton.
1	60	46	1	14	97
2	40	99	2	25	35
3	28	128	3	16	171
4	43	104	4	40	34
5	33	179	5	40	54
6	84	187	6	38	65
7	63	97	7	10	107
8	84	146	8	34	44
9	52	129	9	34	45
10	48	290			
11	28	170			

The quartz sandstones alternating with the conglomerates of the Rand contain hardly any gold. An exception to this is found, however, in the rich reef of Rietfontein, which represents a sandstone very poor in pebbles, and a reef in the Buffelsdoorn mine, almost devoid of pebbles, and yet containing gold. Conversely it is true that by no means all conglomerate beds contain gold in workable quantity.

A peculiar occurrence in the conglomerates of the Klerksdorp goldfield is a layer, 0.5 cm. thick, of bituminous quartzite with a considerable content of arsenic sulphide and the exceedingly high gold value of 143.75 oz. per ton.

Finally an exceptional position is also occupied by the bed called Black reef, quite close to the base of the Cape formation. It is overlain by dolomite, is underlain by a decomposed, tourmaline-bearing eruptive rock, and consists of angular quartz fragments, held together by a cement consisting of rounded pyrite grains.

The innumerable faults traversing the conglomerates are of great importance, both from the geological and practical standpoints. Their fissures are often filled with diabase, which is very common throughout the general Rand area. These igneous dikes, sometimes as much as 30-40 m. thick, have cut off the ore in many mines.

The faults are either transverse fissures, parallel to the dip of the reefs, as for example the great fault of Bocksburg, or they are strike faults, in which, contrary to the usual rule, the foot-wall has dropped down. (See the profile of May Consolidated mine at Johannesburg, Fig. 112.)

In consequence of overthrusts of this kind, the same reef occasionally outcrops twice, as for example the Main reef in the mine field of the Witwatersrand Consolidated Company, where the distance is 120 m. between the two parts.

No impoverishment of the reefs can be noticed in the vicinity of the diabase dikes. On the contrary, in Rose-Deep, Bonanza and other mines, astonishingly rich strikes have been made immediately adjoining such eruptive masses, the ore containing as high as 3 kilograms of gold per ton. Thus for example, exceedingly rich ores were extracted in the Ferreira mine from a portion of the reef wedged in between a decomposed eruptive dike and a fault fissure.

Secondary quartz also occurs as a result of later dynamic processes. These segregations are generally milk-white and sometimes occur in tufts, sometimes in short veins traversing a conglomerate bed. These fillings of strain fissures occasionally carry in their quartz some iron pyrite, copper pyrite, galena, blende and sometimes also gold.

The first gold was discovered in the conglomerates of the Witwatersrand by a certain Mr. Arnold, in 1884, on the Geldenhuis farm. As early as 1885, the Struben Brothers began gold mining on the conglomerate outcrops of the Gute Wilge Spruit. In 1886, the region was declared a public goldfield by the government. The town of Johannesburg quickly grew up. The discovery of coal as early as 1887 at Bocksburg facilitated the rapid development of gold mining. In 1893, as many as 70 mines were in operation, with a total output of 2,009,601 tons of conglomerate and a net return of 45,980 kilograms of gold. Shortly before the war of 1899-1900, Johannesburg numbered 70,000 inhabitants, and almost 100 companies were at work on the Rand, 55 of them with good success. The most important mines are the Robinson, which alone furnishes 1/10 of the total gold output, Langlaagte, Crown Reef, Jumpers, Simmer and Jack, Roodeport, Meyer & Charlton, May Cons., Ferreira, Geldenhuis, New Primrose, Nigel, Jubilee, Salisbury, and Worcester. In 1898, the gold production reached 109,000 kilograms.

Genesis of the Gold-bearing Conglomerates of the Witwatersrand.

The views upon the origin of these great gold deposits are still widely at variance. Four main hypotheses have been advanced:

1. Mechanical Hypothesis.

According to this hypothesis, the conglomerates are 'fossil' stream gravels, that is to say, deposits of pebbles and sand, whose gold particles were washed into them in a purely mechanical way. This assumption is at once refuted by the microscopic condition of the gold in the conglomerates already described. The gold particles have no resemblance whatever to mechanically transported gravel gold. Neither is their distribution in the reefs such as is customary in gravels. Moreover, the hypothesis is gainsaid by the absence of gold in the interior of the quartz of the pebbles.

2. Chemical Segregation Hypothesis.

According to this *precipitation* theory, as it may be briefly called, advocated especially by Penning, DeLaunay and Stelzner, the gold was deposited as a purely chemical precipitate from sea water close to a coast, and simultaneously with the deposition of the gravels. This appears improbable (1) because in the disturbed water of the littoral zone, where gravel might be transported and deposited, such a precipitation is hardly conceivable; (2) because it ought to have taken place at least to the same extent during the deposition of the sand furnishing the quartzites; (3) because the exceedingly slight gold content of the present seas, demonstrated by Liversidge and others, does not suffice, so that recourse must be had to gold brought by mineral springs, a theory which involves the improbability that these springs should have ceased whenever sand strata were deposited, and reappeared whenever gravel was deposited.

The recent experiments of J. R. Don[1] have in fact thrown great doubt on the possibility of a precipitation of the minute gold content in sea water. Not one of the reagents occurring in nature was found by him capable of effecting a precipitation of gold from sea water.

3. Chemical Redistribution of Placer Gold.

This view was advanced by E. Cohen, endorsed by F. Posepny, and probably argued most exhaustively by G. F. Becker. The last named author compared the conglomerates with the marine gravels found at the present day on the coast of California, Oregon and Alaska, gravels whose material is said to be undoubtedly derived from eroded gold quartz veins. In these recent marine gravels, too, the gold is said to be but rarely found in the pebbles themselves; it exists in them in an evidently non-crystallized condition; its distribution, in contrast with fluviatile gravels, is said to be approximately uniform throughout the entire thickness, and finally nuggets are said to be absent from these gravels. The recrystallization of the gold, which he admits to be extensive in the Rand, he associates with the eruption of the diabases. This theory is certainly very inviting, but it does not

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes.' *Trans.* Am. Inst. Min. Eng., 1898, Vol. XXVII, pp. 564–568.

meet one weighty objection: to wit, that, if it were correct, there is all the more reason why the gold ought to be present in the beds of quartzitic sandstone, since the material of recent marine gravels is always mainly sandy.

4. Theory of the Subsequent Introduction of the Gold into the Conglomerates.

The noteworthy view called very aptly the theory of *"subsequent mineralization and impregnation"* of the conglomerates, has been especially advocated by Gardner F. Williams, J. S. Curtis, J. Kunz, K. von Kraatz, P. Krause and John Hays Hammond. It may be described as being the prevalent view among the Johannesburg mining engineers. The subsequent invasion of gold-containing solutions, assumed by this theory, is usually associated with the eruption of the diabases. The presence of numerous secondary hornblende spicules, verified by the present author, in the cement of the conglomerates, is a strong point in favor of such subsequent mineralization of the beds, formerly porous in themselves and further disrupted by dynamic processes. In this hypothesis, this pyrite is usually regarded as primary, and at the same time as a precipitant of the gold, a precipitation of gold from very dilute solutions of gold chloride and sodium chloride by pyrite having in fact been experimentally verified by Johansson and Liversidge. This theory is further borne out by the unequal distribution of the gold in the conglomerate beds and an occasional enrichment near eruptive masses. Finally, it is supported by the fact that elsewhere in the Transvaal, as in the Lydenburg district, undoubted typical sediments, to wit, the dolomites of the Malmani horizon, have been mineralized by solutions which deposited gold and quartz together with copper ores. A further argument is derived from the observation that at a horizon much higher geologically, the Black reef, there is a repetition of the gold content of a conglomerate, indicating, in a general way, a lack of constancy of horizon of deposits of this kind. At the same time, the main objection against this theory must not be passed in silence, namely, that only a few of the beds, and not all of the conglomerate beds, appear impregnated with gold, that is to say, no uniform zone of impregnation passes through all the strata of the Witwatersrand, either along fault fissures or eruptive dikes. In reply, however, attention is to be called to the original very unequal permeability of such rock strata. Thus the cement of the beds known to be poorer, such as Main reef, Elsburg, Bird and Kimberley reefs, seems, through more abundant mixture of the finest quartz sand, to have acquired a greater density than the other richer beds.

In the present state of knowledge, the fourth hypothesis seems as yet to possess the greatest probability, although the question can by no means be regarded as decided.

2. *The Conglomerates of the Tarkwa Goldfield in West Africa.*

There has recently been a considerable production of gold from the conglomerate beds found on the Gold Coast of West Africa. The conglomerates of that region, according to S. J. Truscott[1], are found between the rivers Ancobra and Prah. They form intercalations in a sandstone composed of quartz and decomposed feldspar grains, with some magnetite and ilmenite, having a cement that is sometimes calcareous. The bed is traversed by a multitude of quartz veinlets. Besides conglomerate, the sandstone also contains intercalations of dolomite. Underlying the whole aggregate are quartz diorites, while phyllitic slates form the overlying strata. The beds form a syncline striking northeast, whose southeast limb has been studied in detail. The dip of the beds that are mined varies between 20 and 60°. Borings disclosed several masses of epidiorite.

The most important bed is the Tarkwa reef, whose thickness sometimes exceeds 1 m. The conglomerate pebbles consist of light gray, more rarely milk-white quartz, with some decomposed feldspar rock. The cement is made up of fine-grained quartz with muscovite, and occasionally of secondary quartz. Scattered through this cement there are grains of decomposed feldspar, magnetite, ilmenite and crystals of rutile, as well as gold. The gold is but rarely distinctly visible, is not accompanied by any pyrite, and has a very uneven distribution. The gold in the conglomerate, after picking out the barren pebbles, varies between 4 and 16 grams per ton, while some rich streaks have an average of 40 grams per ton. The great purity of the gold (940 to 960 fine) is remarkable, far exceeding that of the Witwatersrand gold. The richest ores occur in those portions of the bed in which the cement contains much magnetite.

Genetically, the Tarkwa occurrence may possibly not be identical with the preceding example of this class.

(f) Antimony Deposits.

1. *Antimony Deposits of Westphalia, Prussia.*

At two points in Westphalia, viz.: at the Casparizeche mine near Uentrop in the Arnsberg field and at the Paussauf mine near Nuttlar in the Brilon field, bedded antimonial deposits are known[2].

[1] S. J. Truscott: 'The Witwatersrand Goldfields,' 1902, 2d ed., pp. 487–508.

[2] L. C. Buff: 'Ueber Gangbildungen, welche lagerartige Entstehung zu haben scheinen' (Spiessglanzerze auf der Casparizeche). Karsten's *Archiv* f. Min., 1833, Vol. VI, pp. 439. A. W. Arndt: 'Ueber den Bergbau auf Spiessglanz am Silberberge bei Arnsberg.' Elberfeld, 1834.

"The occurrence in the Casparizeche, according to official data[1], is associated with the uppermost strata of the Culm, the 'Platten' limestone, which at this place forms the easternmost end of the eastward dipping Arsnberg anticline, and near by is overlain by barren sandstones. At the outcrop of the Culm strata, the top of the anticline is wanting, only the two flanks being present (northwest and southeast flanks), the southeast flank having been exposed to a distance of 1,100 meters in the search for antimony ore.

"The main anticline contains numerous smaller sharply bent and fractured folds, running in the same direction as the main fold, and the continuity of the strata is interrupted by many faults, running in all directions. The normally light-colored and firm rock is dark-colored where the ore occurs and is quite crumbly." On the southeast limb of the anticline five ore-bearing beds are known. Within these beds, but never in all at the same place, but only here and there, the ores, containing stibnite, and in the outcrop antimony ocher, form nest-like segregations 5 to 15 cm. thick. The ore forms sheets and rods extending outwardly nearly to the limiting surfaces of the strata, or occurs interspersed with the rock in small particles. Similar conditions prevail on the north flank of the anticline, except that the ores there consist mainly of antimony ocher and are less pure.

The antimony deposit of the Passauf mine near Nuttlar occurs in a series of barren sandstones forming the southwest flank of the Wiemertberg, near Vöckinghausen. There are three ore-bearing beds, the bulk of which is made up of silicious shale and black clay, with bunches of stibnite.

The presence of antimony ores at two entirely different horizons in the Carboniferous formation, together with their association with much fissured regions, renders the epigenetic nature of these deposits very probable.

The possibility of the lateral immigration of antimony ores from fissures into and along beds of shaly rocks is clearly proved by the following example:

2. *The Antimony Deposit of Brück.*

At Brück on the Ahr, in the area of which Adenau is the center, near the Eifel, antimony ores are found in the Paleozoic graywacke slates, which strike north-northeast and dip west at 45°. Within a north-south zone 24 to 32 m. in width, and exposed by workings for at least 160 m., the slate is greatly fissured and is traversed by numerous northeast veins, which dip

[1] Description of the Bergreviere Arnsberg, Brilon and Olpe, as well as those of Fürstenthümer, Waldeck and Pyrmont. Published by Kgl. Oberbergamt, Bonn, 1890, p. 158.

south at 40 to 50°, and which contain stibnite, pyrite, quartz and brown-spar. From these fissures, according to Erbreich[1], a part of the ore has penetrated between the strata and along other bedding planes of the gray-wacke schist.

3. *The Bedded Antimony Deposits of Sidi-Rgheiss in Algeria.*

The antimony deposits of Sidi-Rgheiss are situated in the southwestern part of the province of Constantine and have been mined at Sempsa and at Djebel-Hamimat. They are found in the midst of steeply dipping dark clays and limestones of the lower Neocomian, but are not confined to any definite horizon of that formation. The ore, according to Coquand[2], is in part a compact antimony oxide, milk-white to grayish in color, and with conchoidal fracture, and in part a granular crystalline variety containing druses, from which the Algerian senarmontite crystals found in so many collections have been obtained. The antimony oxide shows at times small superimposed bunches of needles of stibnite, with silky luster, some of which have been secondarily transformed into red antimony blende. The deposits form very irregular masses, parallel, however, to the stratification and without any accompanying gangue minerals.

The remarkable occurrence of isolated crystals of senarmontite in the midst of a limestone containing belemnites convinced Coquand that the ore and limestone were of simultaneous origin, and formed in sea water, to which mineral springs had contributed a considerable quantity of antimony. It seems, however, as remarked by Fuchs and DeLaunay, that the observed conditions are better explained by assuming a subsequent replacement of the limestone by the ore.

Conclusions Upon Epigenetic Ore Deposits.

The two fundamentally opposite genetic views, whose rivalry at the present day is keener than ever before in the history of economic geology, have been presented and weighed one against the other in the descriptions which we have given of numerous stratified deposits of sulphide ores of the most diverse composition and age.

[1] Erbreich: 'Geogn. Beschr. der Spiessglanz-Lagerstätte,' etc. bei dem Dorfe Brück. Karsten's *Archiv* f. Min. 1827, Vol. VI, pp. 44–53.

[2] Coquand: 'Description des mines d'antimoine oxydé exploitées dans les environs de Sidi-Rgheiss.' *Bull.* de Soc. Géol. de France, 1852, p. 342. Fuchs and De Launay: 'Traité,' Vol. II, p. 205. L. De Launay: 'Les Richesses Minérales de l'Afrique.' Paris, 1903, p. 335.

The *sedimentary* theory assumes that strata consisting of sulphide ores, sometimes of considerable thickness, have been deposited on the bottom of the ocean or sometimes of a shallow coastal sea, exactly like limestone or rock salt beds, or at any rate purely chemical precipitates of such sulphide ores were deposited by sea water in small particles associated with the normal sediments.

The other is the *infiltration* theory, according to which such deposits are due to a subsequent mineralization of ordinary sediments, at a much later geologic period, by means of an infiltration of ore solutions derived from fissures.

We believe that the reader must have gained the conviction that the conditions of structure and position actually observable argue, in most instances, rather in favor of the second hypothesis. This is particularly true of the beds of sulphide ore in crystalline schists. The lack of constancy of position in otherwise uniformly stratified ore deposits, the limitation of the beds to portions of rock strongly influenced by dislocations and traversed by eruptive rocks, the occasional occurrence of offshoots (Ueberschneidungen) at the boundary of such orebodies with the sediments, the occasional presence of vein-like spurs and stringers, and above all the microscopic relations of the ores to the other rock constituents, which often point to a later segregation of the metallic compounds—all these speak in favor of the infiltration theory.

It will contribute to the further clearing of the question, if we consider how and to what extent chemical precipitates of sulphidic ores are now forming at the bottom of lacustrine and marine waters of the present time.

The best studied phenomenon of this class is the secretion of iron pyrite and marcasite in peat bogs, swamps and under similar conditions, wherever organic substances decay under imperfect access of air, and iron-bearing solutions are present. The best known instances are the strata of iron pyrite and marcasite forming at the bottom of the so-called mineral moors of Franzensbad, especially in the great moor called Soos near that place and near Marienbad[1]. They occur mainly in the form of pseudomorphs enveloping plant stalks, but in part also in large lumps and plates. The conditions here are especially favorable to the precipitation of ore, because the numerous mineral springs rising in the moor continually introduce iron salts into the water thereof, in particular sulphate of iron, which to some extent undergoes a direct reduction to iron sulphide by the plant remains

[1] H. Loretz: 'Ueber die in den fossilen Brennstoffen vorkommenden Mineralien.' *N. Jahrb.* f. Min. 1863, p. 661. E. Palla: 'Recente Bildung von Markasit im Moore von Marienbad.' *N. Jahrb.* f. Min. 1887, Vol. II, p. 5. O. Bieber: 'Das Mineralmoor der Soos.' Marburg, 1887, p. 30. C. Ochsenius: 'Ganz junge Bildung von Schwefelkies.' *N. Jahrb.* f. Min. 1898, Vol. II, p. 232.

decaying at the bottom, while by far the greater part are precipitated as oxidic compounds.

Occasionally, the formation of sulphides of other rarer metals, though not on so large a scale, has been observed as a sequel to this kind of reduction phenomena. Thus in the lead mine of Bennerscheid, east of the Siebengebirge, according to Nöggerath and Bischof, old mine timbers were found to be coated with crusts consisting for the most part of zinc sulphide, with silicic acid, alumina, etc., water and some cadmium sulphide[1]. In true sediments, however, such phenomena are not known.

That decaying animal substances may also effect such a reduction is proved by Bakewell's observation that a mouse, lying in a bottle containing a solution of green vitriol, became coated with small crystals of iron pyrite[2]. This explains the frequent occurrence of fossils mineralized by iron pyrite or marcasite in almost all known formations, as in the case of the ammonite shells which have been more or less replaced by that ore.

An example of the recent formation of iron pyrite in sea water was reported by Forchhammer from the coast of Bornholm, where decaying fucoidal seaweed comes in contact with an iron-bearing spring water. The reaction in this case takes place indirectly[3]. The sulphates of the seaweed are reduced by the process of decay to sulphides, which, on rapid decomposition in the presence of carbonic acid, yield carbonates and hydrogen sulphide. The latter precipitates the iron as iron sulphide from the solutions brought by springs into the small bay, so that the pebbles on the sea bottom are covered with a beautiful yellow film. G. Bischof inferred from this that the crystals and granules of iron pyrite in the alum schist and in similar rocks were likewise formed by the action of decaying fucus remains on the iron-bearing sea mud.

On the bottom of some parts of the sea considerable amounts of hydrogen sulphide are developed by the reduction of the alkaline sulphates dissolved in the water, in consequence of the decomposing organic detritus, the gas occurring in large enough amount to precipitate metallic salts, especially in the depths of the Black Sea[4].

N. Andrussow describes a mud containing ferrous sulphide from the Black Sea[5], as follows:

"The mud of the deep-sea bottom is for the most part of two kinds: the black mud on the slopes (between 540 and 1,290 m.) and the dark blue mud on the level bottom of the sea.

[1] G. Bischof: *Lehrb.* d. chem. Geologie. 2d ed., 1863, Vol. I, p. 559.
[2] Fuchs: 'Die künstlich dargestellten Mineralien.' p. 55.
[3] Cited by Bischof: *Lehrb.* d. chem. Geol., 1st ed., 1863, Vol. I, pp. 926–927.
[4] J. Walther: 'Einleitung in die Geologie,' 1893–4, p. 661.
[5] N. Andrussow: 'La Mer Noire.' *Guide* des Excursions du VII. Congr. Géol. Intern., 1897, Vol. XXIX, p. 13.

"The black mud of the slopes, which is very tough and sticky, always becomes gray the moment it is exposed to the air. The discoloration is due to the presence of ferrous sulphide (FeS), which oxidizes very quickly in the air. Under the microscope the coloring matter appears partly in the form of small isolated globules, partly as an impregnation between the sand grains. The presence of such globules in the interior of diatoms is of particular interest.

"By dredging, masses of blue mud are sometimes obtained in the same region, which occasionally contains nail-shaped concretions of ferric sulphide. This mud probably lies under the black mud.

"The dark blue mud of the deep-sea bottom is less dense and encloses many diatoms, especially pelagic ones. It also contains FeS, but in less amount, concealed, it would seem, by a more or less considerable amount of $CaCO_3$, which is fine-grained and sometimes gathers into small lumps."

Although the possibility of precipitation of sulphide ores, on a small scale, both from fresh and from salt water, has to be admitted, yet there is nothing forming at the present day that presents an analogy to the formation of such vast pyrite accumulations, in part of varied mineralogic composition, as are found in increasing frequency and size the farther we delve down into the strata of the earth. We do not attach any very great importance to the insignificant sulphide formations of the present day, because we are able to find a better explanation. These remarks are suggested by observations which plainly show that in foliated rocks the ore was introduced through fissures.

We refer particularly to an example from Burgundy, noted by Bonnard (1825-28), and later described again by A. Daubrée[1].

Southeast of Avallon, on the high plains of Étaules, a granite mass is traversed by numerous veins of chalcedony, hornstone and quartz, but containing also fluorspar, barite, galena and iron pyrite, thus showing that they belong to the barytic lead formation. Above the granite is an arkose belonging to the Lias, the lowest member of the Jurassic group. Along the plane of deposition of this arkose, the solutions rising through the vein fissures have overflowed, as it were, and have completely impregnated the porous rock with their deposits. These relations are shown in Fig. 215 after Michel Lévy and Ch. Velain. The siliceous minerals form in this case either merely the cement of the arkose or solid streaks in which fluorspar, barite and galena occur, both disseminated and in a compact form, filling small stringers and druses. The shells of *Gryphaea* and other *Con-*

[1] A. Daubrée: 'Les Eaux Souterraines aux époques anciennes.' Paris, 1887, p. 126.

chylia occurring in the lowest Lias are in such cases always completely silicified.

A similar occurrence, and one in which rich and workable ore beds have been produced by lateral infiltration from vein fissures, occurs at the Enterprise mine, near Rico, Colorado.

Reference must be made here also to the interesting conditions disclosed by the Silberfennig mine in the Hohen Tauern[1]. The gold veins at that place cut the gneiss, but abut against the unconformably overlying calcareous mica-slate. Some of the overlying beds are impregnated with pyrite, galena, zinc-blende and siderite, entire layers of spathic iron occurring parallel to the stratification, while galena and blende have been worked to a less extent. The immigration of the ores from the fissures seems in this case quite certain.

Fig. 215.—Section through the high plains of Étaules, near Avallon, France.

In this work we have repeatedly had occasion to speak of ore deposits whose dimensions and form cannot be satisfactory explained by simple infiltration of beds of suitable but originally barren rock, or through a metasomatic replacement of congenial strata, but seem to require an antecedent cavity formation. Broken Hill in particular, as well as many Norwegian pyrite deposits, would seem to need this interpretation. An attempt to show this in detail is made by Th. Kjerulf[2]. His idea of the processes at work in such cases is best and most briefly set forth by a view of his model given in Fig. 216. It shows that a folding and a subsequent overthrust may actually produce cavities intercalated parallel to the stratification, exactly similar in shape and occurrence to the ore masses of the Norwegian pyrite beds. Further investigations are needed in order to pick out all the cases in which this origin is properly to be assumed. Such examples should perhaps be more properly referred to as stratum veins, but such discrimination seems as yet impracticable.

Much as the sedimentation theory and the infiltration theory differ from

[1] 'Unters. des Bergb. in den Hohen Tauern.' Vienna, 1895, *Herausgeg.* vom k. k. Ackerbau-M., p. 77.

[2] Th. Kjerulf: 'Geologie von Norwegen.' Translation by A. Gurlt. Bonn, 1880, plate XVIII, Fig. 263.

each other in their respective explanations of the genesis of epigenetic ore deposits, they were found to agree in one point, namely, in assuming that the ores were deposited from solutions. Even the mode of precipitation of the sulphides from such solutions is in many cases conceived to be alike by the advocates of both theories, inasmuch as they point to the reducing agency of bituminous substances. In many cases it is found that the epigenetic ore deposits in question even now enclose such substances.

A sort of compromise theory was recently advanced by F. Klockmann, formerly a zealous adherent of the pure sedimentation theory. He first applies his new explanation to the pyrite beds of the Rio Tinto field. These, according to him, are "concretionary segregations within a plastic clay mud (consolidated as a slate) impregnated with the chemical elements

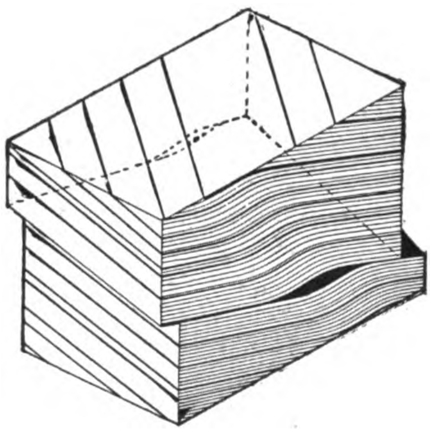


Fig. 216.—Model of slip cavities subsequently filled by ore as 'ore rods.'

of the pyrite." The preceding saturation of the mud with these elements he conceives as connected genetically with the eruptive masses of the locality (effusive according to him), which he describes as "bringers" of ore[1].

A new idea in the explanation of the genesis of certain epigenetic ore deposits has recently been advanced by E. Kohler[2], who calls attention to the importance of processes of adsorption.

By adsorption is meant the property of porous carbonaceous and colloidal substances, such as gelatinous silicic acid, as well as kaolin or clay, to retain a part of the substances dissolved by highly dilute solutions which pass through them. Thus a one per cent aqueous solution of copper-ammonium

[1] F. Klockmann: 'Ueber das Auftreten und die Entstehung der südspanischen Kieslagerstätten.' *Zeit. f. Prak. Geol.*, April, 1902.

[2] E. Kohler: 'Adsorptionsprocesse als Faktoren der Lagerstättenbildung und Lithogenesis.' *Zeit. f. Prak. Geol.*, 1903, pp. 49–59.

sulphate passed through a filter coated with kaolin loses its entire copper content as copper oxide, the filtrate consisting only of a solution of ammonium sulphide. This property of adsorption is attributed by Kohler to the clays of many epigenetic deposits, for example, that of the lead-bearing stone of Commern, the Freihung lead-bearing sandstone, etc., in explanation of the deposition of ore by metalliferous solutions seeping in from fissures. This idea is worthy of careful consideration, especially since in lodes themselves masses of clay and kaolin often prove to be richly impregnated with ore. A good analogy is also found in the kaolins of Broken Hill, so rich in horn silver, the Australian students of that deposit having years ago compared the action of those kaolins with that of a filter.

Less convincing is Kohler's attempt to explain the ore content of the copper schist by an absorption of the metallic salts supposed to have been dissolved in the Zechstein sea, by a subsiding turbidity during the process of sedimentation, a process he invokes in order to sustain the deep-rooted idea of the simultaneous origin of sediment and ore.

B. EPIGENETIC ORE STOCKS.

The name *epigenetic ore stock* was given on an earlier page, for the sake of brevity, to all the stock-shaped, pocket-shaped or tube-shaped (chimney) orebodies found in limestones or dolomites, and formed essentially by means of a metasomatic replacement of the carbonates of the original rock, by ores and accompanying non-metallic minerals. As will be shown in discussing the several examples, the process of replacement, in the formation of these deposits, was perhaps often accompanied by the filling of pre-existing cavities, leached out or dissolved out at an earlier time by solutions quite different from those that finally supplied the ore.

The epigenetic ore stocks, like ore-bearing veins, are grouped according to the predominant or most characteristic metals, while in each group the examples may be further arranged according to the age of the country rock, although this factor is genetically of but subordinate importance.

(a) Epigenetic Stocks of Iron and Manganese Ores.

1. *The Iron Ores of the District of Elbingerode in the Harz.*

At the Büchenberg, in the Gräfenhagensberg forest district, near Elbingerode, iron ore deposits have been worked for more than 500 years[1].

[1] Important publications: Hauchecorne: 'Die Eisenerze der Gegend von Elbingerode am Harz.' *Z.* f. d. B.-, H.- u. S.-W. im preuss. St., 1868, Vol. XVI, p. 199. M. Koch: 'Gliederung und Bau der Culm- und Devonablagaerungen des Hartenberg-Büchenberger Sattels.' *Jahrb.* d. preuss. geol. Landesanst., 1895, Vol. XVI, p.131.

The structural conditions are rather complicated, but have been carefully worked out and explained by M. Koch. According to him, the Paleozoic strata at the Hartenberg and Büchenberg form an anticline within which the following strata are developed, from above downward:

Graywackes	Culm.
Posidonia slates	
Adinoles, whetstones and silicious slate	
Cypridina slates	Upper Devonian.
Clymenia limestone	
Younger diabase tuff and amygdaloid	
Stringocephalus limestone	Upper Middle Devonian.
Keratophyre with intercalations of tuffs and tentaculite slates	
Older platy trap and diabase amygdaloid	

The iron ores of this region have for the most part been produced by a gradual displacement of the original calcium carbonate of the Stringocephalus limestones by iron compounds. They consist mainly of calcareous and silicious red and brown hematite and in part also of magnetic iron ore. To a subordinate extent hematite deposits, some of them workable, have also been produced from the keratophyre (orthoclase porphyry) during its decomposition, as a result of an enrichment formed by the iron, not only from the magnetite of the rock, but also from ferruginous silicates and from iron pyrite. Such ores, with still fresh keratophyre cores, outcrop, for example, on the east side of the Gräfenhagensberg open-cut. Parts of other deposits are also worked in the Bunte Wormke mine near Mandelholz and in the Oberer Stahlberg mine near Neuwerk. The ores are fine-grained to dense, clayey, silicious red hematites, with some magnetite.

The Stringocephalus ores attain a thickness of 30 m. (98 ft.) at the Büchenberg, and have been opened to a length of about 4 km. (2.4 miles) in the strike, mainly by open-cuts, which have left extensive pits (Blaue Pinge). The mines of that region comprise altogether six fields. The deposits are found to be for the most part steeply tilted, dipping as high as 50 to 70° and more north.

South of the Büchenberg lies a second iron ore deposit, which is worked by open-cut and drifts at Tönnichen. The ores occur in nearly horizontal beds forming a basin, and carry two intercalations, both of the diabase tuffs, which also forms the floor, and of the Stringocephalus limestone. The deposit is more than 1,200 m. (3,936 ft.) long. The ore, especially that of the lower divisions, contains recognizable fossils of the Stringocephalus stage.

In detail, the strata both at the Büchenberg and at Tönnichen are much disturbed by folding and overthrust, as may be learned from Koch's description.

It seems almost certain that the iron for the mineralization of the Stringocephalus limestone was furnished by the decomposition of the diabase tuffs and amygdaloids.

Quite analogous conditions exist in the iron ore deposits in the Rhenish schists at Brilon, Wetzlar, Weilburg, Dillenburg and elsewhere, which need not be further discussed here[1]. This group also includes the iron ores associated with diabases and diabasic tuffs, in the Devonian of Moravia and Silesia[2], for example at Bennison in Silesia.

2. *The Iron Ore Deposits of the Iberg, near Grund, in the Harz.*

According to F. Klockmann[3], the massive upper Devonian limestone of the Iberg and the Winterberg, near Grund, in the upper Harz, is cut up to an extraordinary degree by fractures. The long veins, which traverse the Culm graywackes and slates, show a complete change of behavior in this rock. They are resolved into a tangle of fissures and clefts, only a few of which are marked by any notable extent or uniformity in direction. The waters circulating through all these open courses produced rather extensive and very irregular or tube-shaped cavities, especially at the points where fractures intersect or unite. The cavities are filled with the residue from the leaching of the limestone, a red cave-clay, whose tenacity causes it to be sought after as material for the tamping of drill holes. Some of these cavities carry also barite, as well as calcspar and quartz, but pay-ores only occur within this Devonian limestone, along the continuation of the Prinz-Regenter and the Oberen veins. On the other hand, the Devonian limestone has in many places been replaced by iron ore, through a metasomatic replacement of the calcium carbonate by iron carbonate, the spathic iron ore being, however, now almost everywhere secondarily transformed into brown hematite. The other isomorphous carbonates mingled with the iron carbonate were in this secondary alteration segregated as calcspar, dolomite spar, manganite, psilomelan and wad. The accompanying minerals are barite, quartz, pyrite, copper pyrite, bornite, malachite and asphalt.

The limestone stock of the Iberg is at some places completely dotted with pockets and bunches of iron ore, often arranged in rows or strung along the fissures. Some of these ore stocks are 130 feet thick.

[1] W. Riemann: 'Das Vorkommen der devonischen Eisen-und Manganerze in Nassau.' *Zeit. f. Prak. Geol.*, 1894, pp. 50–57.

[2] A. Pelikan: 'Ueber die mährisch-schlesische Schalsteinformation.' *Sitzungsb.* d. k. Ak. d. W. in Wien, math.-naturw. Kl., 1898, Vol. CVII.

[3] F. Klockmann: *Berg- und Hüttenwesen* des Oberharzes. Stuttgart, 1895, pp. 62–65.

The mining industry of Iberg, formerly very active, came to a standstill about the eighties.

3. *The Iron Deposits in the Devonian Rocks of the Southern Ural, Russia.*

Extensive iron deposits, mainly brown hematite, are associated with the lower Devonian limestones of the Pervukhina district near Ust-Katavsk, in the southern Ural[1]. They outcrop on the slopes of Mounts Shuida, Irkuskan and Bulandikha, and are exploited especially near the mining town of Bakal.

The steeply upturned and elevated Devonian strata in this region, in part folded into an anticline, show the following section:

3. At the top, quartzites and sandstones, forming odd-shaped mountain crests and rocky heights. The débris blocks cover the ground far and wide.

2. Gray, yellowish-gray, greenish or reddish slates, with intercalations of dolomitic limestone, sometimes of great thickness.

1. Quartzitic and sericitic shales, black and gray dolomites and clay slates with the ore deposits.

All the strata are traversed by numerous diabase intrusions, forming dikes, sheets and sills and perhaps also genuine contemporaneous flows.

The orebodies, at some depth, consist of spathic iron-ore, which is distinctly seen to end against the dolomitic limestone, and is thus recognized as a later replacement product. In the upper workings the spathic iron ore has been transformed into brown hematite, which at present constitutes by far the greater amount of the output. These brown hematites enclose many cavities, with stalactites of brown hematite hanging down from the roof.

The deposits of Mount Irkuskan are a typical example. The lowest rock is a quartzitic slate, banded in cross fracture, with clay slate above it, capped in turn by several layers of brown hematite. All the strata are more or less upturned. The most extensive iron ore measure has been opened by means of a very large, crater-shaped open-cut. In this cut it is seen that at the top a part of the original limestone stratum has been preserved, whereas farther down it seems to be completely mineralized. Despite the cavernous structure of the hematite, the former stratification of the limestone may still be perceived in it, and one may see very clearly that the ore replaces the limestone along the strike. Of the smaller beds within the blackish-gray overlying shales, the one most distant from the

[1] Th. Tschernyschew: *Guide* 7th Cong. Geol. Inter., Vol. III, p. 31.

large deposit is of interest in that it still consists of spathic iron ore. The series of strata is terminated by a quartzite with beds of conglomerate.

The ores are roasted, alternate layers of ore and birchwood being built up into great heaps, close to the mine. Next they are sent to the iron works of Simsk, Nikolayevsk, Katav-Ivanovsk, Jurezan and Satkinsk,

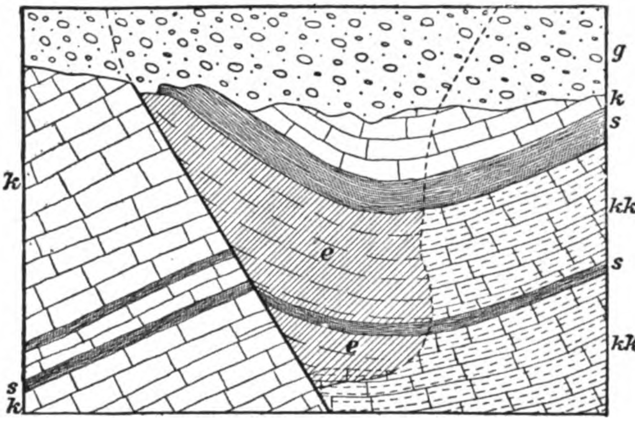


Fig. 217.—Section through the red hematite bed of Crossfield. (Kendall.)
g, boulder clay; k, limestone; kk, highly silicious limestone; s, slate; e, red hematite.

all of which own their mines. In the nineties, the Crown mines of the Bakal district produced annually more than 100,000 tons of ore, and in the other fields about the same amount. The Crown alone has on hand an amount of ore estimated at six million tons, workable by open-cut; the other fields about twenty million tons.

4. *The Red Hematite Ore Deposits in the Limestones of England*[1].

In Cumberland and in the Forest of Dean numerous red hematite deposits were found in Lower Carboniferous limestone, the deposits being very often distinctly associated with faults. From these faults, the iron-bearing solutions, which caused the limestone to be metasomatically replaced by iron ore, seem to have penetrated into the country rock. Sometimes the ore is found to contain Carboniferous brachiopods and corals, partly transformed into hematite, and pseudomorphs of hematite after calcite have also been found. These processes become especially intelligible where thin intercalations of slate in the limestone continue from the latter

[1] Important publications: J. D. Kendall: 'The Iron Ores of Great Britain.' 1893. W. W. Smyth: 'The Iron Ores of Great Britain.' *Mem.* of the Geolog. Surv. 1856, part 1. Phillips-Louis: 'Ore Deposits.' 1896, pp. 176, 247.

into the adjoining ore stocks, without undergoing flexure or interruption (Fig. 217). The deposit shows distinctly that the ore was not deposited in large open cavities, but that the calcium carbonate was dissolved molecule by molecule and replaced by ore. All these hematite deposits were probably originally spathic iron ores and were further transformed, only afterward, by atmospheric seepage water[1].

5. *The Iron Ore Deposits in the Zechstein Dolomite of the Region of Schmalkalden.*

Deposits of spathic iron ore and brown hematite found along the Stahlberg and Klinge faults near Schmalkalden, in the Thüringerwald, which are worked at the Stahlberg and on the Mommel, as well as at the Klinge, are replacements of the dolomites of the zechstein formation[2]. Water charged with carbon dioxide circulated through the faults just mentioned and i even to-day issuing from the Stahlberg fault as the Liebenstein Spring. The water exchanged its $FeCO_3$, metasomatically, for the $CaCO_3$ and $MgCO_3$ of the adjoining dolomite. The iron ores are distinguished by their high manganese content and by the absence of phosphoric acid. Besides those faults, veins of fluorspar and barite are also found.

6. *The Iron Ore Deposits of Amberg.*

The iron ores of Amberg, formerly regarded by Gümbel as Cretaceous sediments, have been demonstrated through the work of E. Kohler[3], and the earlier work of Gümbel[4], to be metasomatic formations, essentially formed by the replacement of Upper Jurassic limestones and dolomites.

The deposits, which have been worked since A. D. 930, occur, according to E. Kohler, "along a northwest fault line which has the direction and is in part a continuation of the Pfahl fault which passes through the eastern part of the Franconian Alb." The ore masses of the Amberg iron district were formed where the great fault zone is crossed by a transverse fault fissure. The deposits consist of a group of large and small bunches and lenses lying in clay and sand, and represent in the aggregate

[1] The investigation of Van Hise on the iron ores of Michigan points to a different origin for these Cumberland deposits, namely, their deposition as replacements by vadose waters in a trough formed by the fault.

[2] H. Mentzel: 'Lagerstätten der Stahlberger und Klinger Störung.' *Zeit. f. Prak. Geol.*, 1898, p. 273. Bücking: 'Gebirgsstörungen südwestlich vom Thüringer Wald.' *Jahrb.* dr. preuss. geol. Landest., 1882.

[3] E. Kohler: 'Die Amberger Erzlagerstätten.' *Geogn. Jahreshefte*, Munich, 1902, pp. 1–50. With full bibliography.

[4] v. Gümbel: *Sitzb.* d. math. phys. cl. d. k. bayr Ak. d. W. Munich, 1893, Vol. XIII, pt. 3, pp. 293–320.

a highly irregular, steeply southward-dipping stock. The ores are mainly brown hematite, in lesser part a saccharoidal spathic iron ore. Fine druses of secondary vivianite are of mineralogic interest. The entire stock of ore and clay rests upon the strongly folded and disintegrated rocks of various Jurassic formations, and, like them, is unconformably overlain by the Cretaceous rocks. The replacement of the Upper Jurassic dolomite by the spathic iron ore is rendered evident by transitions between the two.

Farther northwest are the mines of the Arzberg and at the Etzmannsberg. Here again, Dogger oolites, Malm limestones and dolomites have been replaced by an orebody, along an intersection of faults. Similarly, the ore lens of the Maximilianshütte, situated farther west, is associated with Malm limestones.

The iron ore deposits of the Luitpold mine, near Gross-Schönbrunn, and of the Leonie mine, near Auerbach, are associated with a second main fault, the Vileseck-Auerbach line. The ores here lie between the lower Dogger strata and the dolomites of the Malm, which have been dragged down to this level. Here, too, they consist in part of spathic iron ore, whose structure resembles that of the dolomite.

7. *The Iron Ore Deposits in the Lower Cretaceous at Bilbao.*

The deposits of Bilbao, near the Bay of Biscay, in Spain, are probably the largest and most important examples known of spathic iron ores of metasomatic origin.

Bilbao lies on the Nervion river, which is navigable to a distance of 14 km. (8.4 miles) above the port of Portugalete. The mines occur in a zone

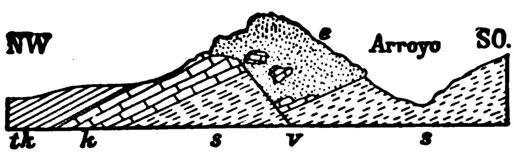


Fig. 218.—Cross-section through the Confianza mine. (De Yarza.) th, clayey limestone; k, limestone; s, sandstone; v, faults; e, iron ore.

about 5 km. (3 miles) wide and 20 km. (12 miles) long, running west-northwest, near the southwest of the river just mentioned, and at Bilbao itself on the northeast side of the river. The most important mining points noted in succession from west to east are: Sommorostro, Galdames, Triano, Moro, Orconera, Miravilla, El Morro and Ollargan.

All the deposits, according to D. R. A. de Yarza[1], occur in the Lower Cretaceous area and are associated with thickly bedded limestones of the Urgo-Aptien stage underlain by micaceous sandstones and frequently overlain by marly limestones of the same age. The ores form very irregular bodies in the midst of the limestone, and in some cases replace it entirely, with the exception of a few as yet unmineralized blocks, as shown in the section, Fig. 218. Sometimes the ore is only found along fissures, and in fact it is visibly dependent on the faults which traverse the Cretaceous rocks, mostly raised into flat anticlines. No eruptive rocks are known in the ore field itself. A zone of ophitic rocks passes at some distance to the northeast[2].

The ores are classified into various groups:

1. Vena, a soft, efflorescent, purple-red hematite.
2. Campanil, a hard, crystalline, red hematite, often accompanied by calcspar rhombohedrons.
3. Rubio, a brown hematite with silicious admixtures.
4. Hierro espatico, spathic iron ore.

We proceed to give for each of these groups the limiting values of 5 to 6 analyses after De Yarza's summary:

	Vena.	Campanil.	Rubio.	H. espatico.
FeO	....	....	....	40.32–54.19
Fe_2O_3	70.12–91.70	69.51–84.01	69.93–83.75	1.71–18.49
SiO_2	1.05–7.19	3.20–6.60	2.50–14.20	0.27–5.95
Al_2O_3	0.65–1.53	2.14–3.80	0.20–3.20	0.17–1.05
Mn_2O_3	0.70–2.24	1.90–5.80	0.78–2.45	0.80–1.18
CaO	0.13–9.27	0.40–4.60	0.50–2.23	2.10–3.70
MgO	Trace–0.46	0.54–1.25	Trace–0.94	0.15–0.69
S	Trace–0.07	Trace–0.02	Trace–0.13	0.04–0.17
P	Trace–0.02	Trace–0.01	Trace–0.94	....
H_2O, CO_2, etc	3.81–19.44	6.30–17.10	3.23–14.67	26.00–37.90
Fe	49.10–64.20	48.65–58.80	48.85–58.80	42.00–48.80

There can hardly be a doubt that originally all the ores of Bilbao were formed as spathic iron ore. The proverb current among the local miners, "*La caliza es la madre del mineral*" (the limestone is the mother of the ore), expresses the genetic connection between limestone and ore. On the other hand, the origin of the iron-bearing solutions is as yet uncertain.

The thickness of the orebodies is sometimes very great, as in the main deposit of Triano, where it is 100 ft. at places.

[1] D. Ramón Adán de Yarza: 'Descripción Fisica y Geológica de la provincia de Vizcaya.' Madrid, 1892. *Mem.* de la Com. del Mapa Geol. de Espagna. M. S. Czyszkowski: 'Explor. Geólog. de la région ferrifère de Bilbao-Sommorostro.' Alais, 1879.

[2] See F. D. Adams: Canadian Mining Inst., 1903. Also, E. Mackay Heriot: 'Iron Ores of Bilbao,' *The Engineering and Mining Journal*, October 3, 1903, p. 510.

The production of all the iron ore fields at Bilbao has risen from 2,800,075 tons in 1881 to 4,782,521 tons in 1901. In 1896 about a half million tons were exported to Germany alone from Bilbao[1].

8. *The Manganese Deposits of Nassau, the Wetzlar District, in Hesse and on the Hunsrück.*[2]

In the regions just named, the surface of the Middle Devonian Stringocephalus limestone, underneath its cover of soil and alluvial material, is very commonly found to be eroded by atmospheric water in a most irregular fashion. Deep gashes, basins and pipes, or flat grooves and troughs, alternate with sharp crests and jagged points or broad ridges and mounds. At the same time the limestone near the surface is often dolomitized. A manganiferous residual formation lies above the dolomite, following all those varied forms of the relief, not only filling the depressions, but also extending across the elevations. The base usually consists of an unctuous, bright yellow or reddish clay, up to 2 m. thick, as shown in the section (Fig. 219.) Lying upon this there is a manganiferous brown hematite, usually in crusts and loose sintery masses, more rarely granular, and holding nests and pockets of pure manganese ore. These porous ores are often replaced by brown-colored clays. The whole is covered by light pink clays, together with pleistocene gravels, sands and clays. The thickness of the mass of manganese ore may rise to 6 m. or in exceptional cases even to 12 m. The harder nests of pure manganese, enclosed in the manganiferous brown hematite, consist of psilomelane, manganite, pyrolusite, polianite and wad. Their interior cavities not infrequently contain kidney-shaped, botryoidal and stalactitic masses, or are lined with small crystals of man-

[1] H. Wedding: 'Die Eisenerze an der Nordküste von Spanien in den Provinzen Vizcaya und Santander.' *Verh.* d. Ver. f. Gewerbfl. Berlin, 1896, pp. 293–321. Also *Zeit. f. Prak. Geol.*, 1897, p. 254. W. Gill: 'The present position of the iron ore industries of Biscay and Santander.' *Journ.* of the Iron and Steel Inst., 1896, II, pp. 36–100.

[2] A. v. Klipstein: 'Ueber die Dolomite der Lahngegenden und das Vork. von Manganerzen.' v. Dechen's *Archiv* f. Min., Vol. XVII, 1843. C. Zerenner: 'Die Braunstein- oder Manganerz-Bergbaue in Deutschland,' etc. Freiberg, 1861. O. Hahn: 'Geogn. Beschr. des Districtes der Lindner Mark,' etc. *Z.* d. D. G. G., 1863, Vol. XV, p. 249. W. Riemann: 'Das Vorkommen (etc.) des Braunsteins im Kreise Wetzlar.' *Z.* f. d. B.-, H.- u. S.-W im preuss. St., 1862, Vol. X, pp. 2–12. Also 'Eisen-und Manganerze in Nassau.' *Zeit. f. Prak. Geol.*, 1894, pp. 50-57. A. Buchrucker: 'Das Manganerz-Vork. am Hunsrück.' *Jahrb.* d. preuss. geol. Landesanst., 1895, Vol. XVI, pp. 1–9. F. Beyschlag: 'Das Manganerz vorkommen der Lindner Mark bei Giessen in Oberhessen.' *Zeit. f. Prak. Geol.*, 1898, pp. 94–96. R. Delkeskamp: 'Schwerspatvorkommnisse in der Wetterau und in Rheinhessen und ihre Entstehung zumal in den Manganerzlagerstätten.' *Notizbl.* d. V. f. Erdk. Darmstadt, 1901, series IV, pt. 21, pp. 47–83. Same author: 'Hessische und nassauische Manganerzlagerstätten.' *Zeit. f. Prak. Geol.*, 1901, pp. 356–365. With bibliography. Bellinger: 'Bemerk über Niedertiefenbach,' etc. *Zeit. f. Prak. Geol.*, 1903, pp. 68–70.

ganite and pyrolusite. These ores sometimes also contain nodules of barite, with drusy centers. The presence of fossils, replaced by manganese ores, proves that not only have actual cavities been filled, but the substance of limestone and dolomite has been metasomatically replaced. It is assumed that the Devonian limestones originally possessed a sufficient manganese content to be concentrated, like the clayey residue and the ferric hydrate, during the long period of the superficial solution of the rock, into these manganese ores. F. Beyschlag regards the clays of the Giessen occurrence as products of the secular weathering of clay slates or other Upper Devonian rocks, and maintains an introduction of iron and manganese solutions from elsewhere by means of waters flowing over the surface of the limestone, with accompanying interchange between the limestone and the iron and manganese compounds.

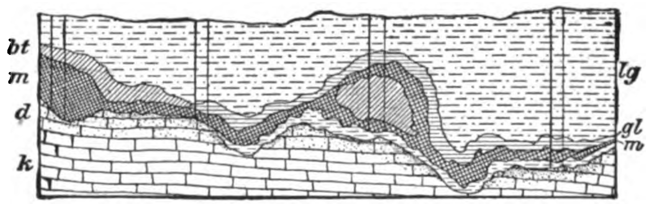


Fig. 219.—Section of the Braune Liesel mine, near Niedergirmes. (Riemann.)
k, limestone; d, dolomite; gl, yellow clay; m, manganiferous limonite; bt, brown clays; lg, clays with nodules.

The vast mass of overlying clays is regarded by Delkeskamp, too, as a younger formation, probably of Pliocene age, whose origin does not coincide with that of the manganese ores.

Formerly the hard manganese ore was separated by a wet process from the lean efflorescent ore and sold separately for the preparation of chlorine. Since the seventies, however, all the manganiferous ores are extracted and used in the iron furnaces mainly as flux for the oolitic 'minette' ores of Lorraine and Luxemburg. In 1900 the production of manganese ore of this kind from the Weilburg mining fields was 2,430 tons, from the Cons. Schlossberg mine, of the Regierungsbezirk of Wiesbaden, 3,460 tons, and for the entire mining district of Bonn, 57,954 tons.

Precisely similar manganese ore deposits occur in the zechstein dolomite at Morsberg near Vierstöck, at Erzbach, Rohrbach, Bockenrod and Waldmichelbach in the Odenwald[1]. The amount of manganous and ferrous carbonate in the dolomite, as well as the simultaneous occurrence of man-

[1] C. Chelius: 'Erl. zur geol. Karte v. Hessen.' Brensbach sheet, 1897. G. Klemm: Erbach sheet.

ganspar, besides pyrolusite, psilomelane and brown hematite, all indicate that the ores represent weathering products of the dolomite.

As an appendix, mention may also be made of the closely analogous manganese ore deposits at Monte Argentario on the south coast of Tuscany, which also rest on the dissected surface of a limestone[1].

9. *The Manganese Deposits of Las Cabesses in the French Pyrenees.*

The manganese deposits of Las Cabesses and vicinity lie in the Department de l'Ariège, between the valleys of the Salat and the Ariège. The ores are associated with variegated limestones of Upper Devonian age, called griottes, which are widely distributed on both sides of the range. According to Klockmann[2], these limestones are overlain by black slates of the Lower Culm, and underlain by Upper Devonian slates. The deposits are formed at the outcrop of manganese oxides, while at but little depth they consist of rather pure manganese carbonate with but little silicic acid and mere traces of phosphorus. From numerous analyses furnished by the owners, the above named author found the following average composition:

Mn, 40–42%; Fe, 1.5–2%; CaO, 6%; SiO_2, 6–7%; P, 0.04–0.05%.

The ores are compact and are hard to distinguish by their appearance from the surrounding variegated limestone (griotte), in which they occur as exceedingly irregular stocks and funnels. The orebody now worked at Las Cabesses consists in the upper levels of two 'chimneys,' with a cross section 50 m. long and 12 to 15 m. wide. At a greater depth the two ore columns unite into one stock. These orebodies form the hanging-wall of a steeply southward-dipping overthrust fissure, filled with black vein-clay shale (Gangthonschiefer), and are cut off below by a second strike-fault, dipping gently south. Furthermore the ore masses are cut by numerous transverse fractures. These fissures, according to Vital[3], are the channels of supply of the manganiferous solutions, which, according to that author, caused a metasomatic replacement of the limestone by manganous carbonate. F. Klockmann, on the contrary, thinks it probable that a concentration of the manganese primarily present in the former calcareous mud took place during the sedimentation of the limestone itself. This interpretation does not seem to be borne out by the form and arrangement of the orebodies, described by him in detail, and is controverted by their relations to the fissures mentioned above.

[1] A. v. Groddeck: 'Lagerstätten,' p. 258.

[2] F. Klockmann: 'Montangeologische Reiseskizzen.' *Zeit. f. Prak. Geol.*, 1900, pp. 265–275.

[3] According to a report mentioned by Klockmann.

It may be added that elsewhere in the Pyrenees manganese deposits are found, conformably intercalated between Devonian shales or at their contact with limestones, especially between the Vallée d'Aure and the Vallée d'Aran. These strata consist of manganese oxides, passing below into rhodonite and friedelite, so that they are properly referred to the occurrences described on page 109.

(b) Epigenetic Tin Ore Stocks.

1. *Tinstone in a Lower Liassic Limestone of the Campiglia, Italy.*

One of the most remarkable tinstone deposits, rediscovered only recently, but known to the inhabitants of the ancient town of Populonia, is found at the southernmost spur of the mountains of Campiglia, called Monte Valerio[1]. In a limestone assigned by B. Lotti[2] to the lower Liassic, a mass of brown hematite occurs, which in the Cento Camerelle and the Cavina mining works is found to enclose bodies of tinstone. The latter was also discovered later in a pure limestone.

A. Bergeat[3] found the tin-bearing limonite in irregular, many branched stocks in the limestone, as well as in the form of a lode in the neighboring Posidonia slate, and recognized pyrite enclosing tinstone and pseudomorphs after it, together with traces of malachite in the ore. The tinstone forms crystals of columnar habit in drusy cavities of the ore. As noted by that author, the occurrence does not belong to the typical tin deposits, but to the transition form described on page 217.

About 2½ km. (1.5 miles) from the deposit, according to B. Lotti, there is a dome of post-Liassic tourmaline granite, whose underground continuation into that region is not impossible.

At any rate this tin deposit belongs in the group of metasomatic deposits, for the tin ore has undoubtedly replaced the limestone.

2. *Tungsten Ores in Crystalline Limestone in Connecticut.*

At Long Hill, in the town of Trumbull, near Bridgeport, Connecticut, Shepard and Percival[4] long ago described a remarkable deposit of tungsten

[1] G. vom Rath: *Sitzungsber.* d. Niederrh. Ges. f. Natur- und Heilk. March 5, 1877. Also *Zeit. f. Prak. Geol.*, 1894, pp. 324–326. Fr. Blanchard: 'Sulla scoperta della cassiterite a Campiglia.' *Boll.* geol., 1876.

[2] B. Lotti: 'Sulla genesi dei giacimenti metalliferi di Campiglia Marittima.' *Boll.* del R. Comit. geol., 1900, No. 4, 1–11.

[3] A. Bergeat: 'Beiträge zur K. d. Erzlagerstätten von Campiglia Marittima.' N. J. f. M., 1901, Vol. I, pp. 135–156.

[4] E. U. Shepard and J. G. Percival: *Report* on the Geolog. Surv. of Connecticut, 1837–1842.

ore, which later on was more accurately described by A. Gurlt[1]. The tungsten ores replace crystalline limestone and have a close genetic resemblance to tin veins.

A younger metamorphic hornblende gneiss encloses a bed of crystalline limestone 10 to 15 m. thick. Both are traversed (1) by a quartz vein 1.8 m. thick, (2) by a topaz vein 1 m. thick, accompanied on both sides by a selvage of violet-colored fluorspar, quartz, blende and mica (margarodite), as well as some wolframite, (3) by a feldspar vein (albite with some beryl and blende). At the contact plane between the lower hornblende schist and the limestone, the latter, within the area of those veins, contains a stratum 1 to 1.5 m. thick, of scheelite, wolframite and wolfram ocher, with quartz as gangue, as well as with pyrite, epidote, calcite and mica. The wolframite occurs exclusively as a pseudomorph after scheelite. At first, therefore, only calcium tungstate was found.

The occurrence is now reopened (1904) and worked[2].

3. *Tungsten Ores in a Cambrian Dolomite.*

According to Irving[3], granular crystalline aggregates of wolframite have been developed near Lead and Deadwood in the Black Hills of Dakota, within the same dolomite lenses of the Cambrian sandstone that contain the gold deposits described farther on. They form large flat orebodies, containing also some quartz, barite and scheelite. Veins carrying tungsten are known in those mountains, but thus far only in the Nigger Hill and Etta Knob tin fields.

(c) Epigenetic Ore Stocks of Copper Ore.

The Copper Deposits of Bisbee, Arizona.

These deposits[4] occur in Carboniferous limestones in the southeast corner of Arizona. They lie near the Mexican boundary on the east slope of the Mule mountains. The orebodies occur in limestone on the southwest side

[1] A. Gurlt: 'On a remarkable deposit of wolfram ore in the U. S.' *Trans.* Am. Inst. Min. Eng., 1894, Vol. XXII, p. 236.

[2] W. H. Hobbs: 'Tungsten Mining at Trumbull, Conn.' *Bull.* 213, U. S. Geol. Surv., 1903, p. 98.

[3] J. D. Irving: 'Wolframite in the Black Hills of South Dakota.' *Trans.* Am. Inst. Min. Eng., 1901. Also Prof. paper No. 36, U. S. Geol. Survey, 363-9, 1904.

[4] J. Douglas: *Trans.* Am. Inst. Min. Eng., February, 1899. F. L. Ransome: 'Geology and Ore Deposits of the Bisbee Quadrangle.' Professional paper No. 21, U. S. Geol. Surv., Washington, 1904.

of a great fault, and are closely associated with an intrusive mass of granite porphyry. The orebodies form great, irregular sheets in limestone; they are generally parallel to the bedding, but only occur near the fault or porphyry. The limestone forms the fractured southern half of a synclinal basin containing sills and dikes of porphyry. The ores are mainly oxidized, consisting chiefly of cuprite, malachite and azurite, and in part native copper in the upper levels, but deeper down are found with manganese ore and brown hematite, forming bunches, pockets or vast stocks, in a clayey mass rich in iron and manganese. These ore-bearing clays either occur as very bulky and quite irregularly shaped masses in the midst of the limestone, or they rest on the limestone.

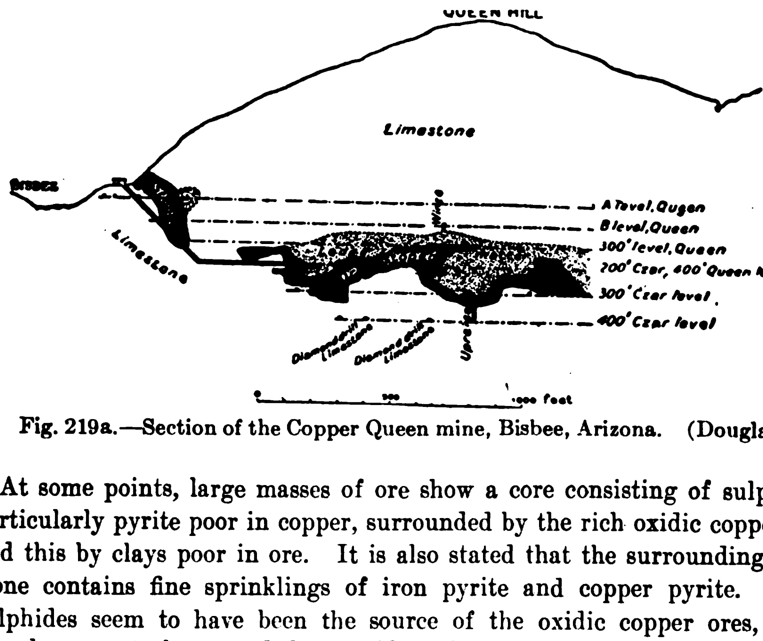


Fig. 219a.—Section of the Copper Queen mine, Bisbee, Arizona. (Douglas.)

At some points, large masses of ore show a core consisting of sulphides, particularly pyrite poor in copper, surrounded by the rich oxidic copper ore, and this by clays poor in ore. It is also stated that the surrounding limestone contains fine sprinklings of iron pyrite and copper pyrite. These sulphides seem to have been the source of the oxidic copper ores, while the clays are to be regarded as residues from leaching, but have probably acted as ore-depositing agents, as explained under adsorption.

The oxidic copper ores are also found, for that matter, on the floor of cavities on whose ceiling copper-bearing calcspar stalactites were observed[1].

A second example belonging to this class is presented by the copper ore deposit of Saint Genevieve, in Missouri.

(d) Epigenetic Stocks of Silver, Lead and Zinc Ore.

Replacement deposits of this kind, in part in connection with genuine

[1] F. L. Ransome: *Bull.* 213, U. S. Geol. Surv., 1903, p. 149.

cavity fillings, occur in calcareous rocks of very diverse ages. In the following pages we give detailed descriptions of the following districts:

1. Laurium, Greece	In crystalline schists.
2. Eureka, Nevada	In the Cambrian.
3. Monteponi, Italy	
4. Mississippi Valley, United States	In the Silurian.
5. Missouri, United States	
6. Iserlohn, Germany	In the Carboniferous.
7. Aachen, Germany	
8. Picos de Europa, Spain	
9. England	
10. Leadville, Colorado	
11. Aspen, Colorado	
12. Upper Silesia, Germany	In the Triassic.
13. Wiesloch, Germany	
14. Raibl, Austria	
15. Bleiberg, Austria	
16. Mapimi, Mexico	In the Cretaceous.
17. Santa Eulalia, Mexico	
18. Sierra Mojada, Mexico	

1. *The Ore Deposits of Laurium, Greece*[1].

The mountainous region of Laurium, in Greece, which contains numerous ore deposits, lies in the extreme southeastern part of Attica. According to R. Lepsius, the crystalline country rock consists of the Lower marble, above this the Kaesariani mica slates and the blue-gray, thinly stratified Upper marble. Finally the Cretaceous formation rests unconformably on the other rocks. The Cretaceous consists of a basal Lower Cretaceous limestone, the so-called "Iron limestone," covered by the green Athenian slates and marls (see section Fig. 220). The Lower marble, the one in which the famous marble quarries of the Pentelicos are located, outcrops at Laurium only in the deepest incisions of the valleys, but forms the main country rock in the deep mines of Camaresa. A characteristic feature of the region is the presence of numerous intrusions of gabbros, all more or less serpentinized. Associated with these there is at Plaka a small granite stock, whose tongues penetrate the sedimentary series as far upward as the Cretaceous marls. This granite is surrounded by a contact zone in which the Kaesariani mica schists are metamorphosed into an augite-epidote-garnet rock.

[1] Most important papers: A. Cordella: 'Le Laurium,' Marseilles, 1871. *Idem*: 'Mineralogisch-geologische Reiseskizzen aus Griechenland,' Liepzig, 1883. R. Nasse: 'Mittheilungen über die Geologie von Laurion und den dortigen Bergbau,' Z. f. d. B.-, H.- u. S.-W. im preuss. St., 1873, Vol. XXI, pp. 12-22. B. Simonet: 'Laurium,' *Bull.* de la Soc. de l'industrie minérale, St. Étienne, 1883, 2d series, Vol. XII, p. 641 *et seq.* R. Lepsius: 'Geologie von Attika,' Berlin, 1893, p. 63 *et seq.* J. J. Binder: 'Laurion: Die attischen Bergwerke im Alterthum,' Laibach, 1895. M. F.: 'Die geologischen Verhältnisse der laurischen Erzlagerstätten,' *Zeit. f. Prak. Geol.*, 1896, p. 153. A. Κορδέλλα.'Ο μεταλλεύτικος πλοῦτος τῆς 'Ελλάδος. 'Εν 'Αθήναις. 1902, C. v. Ernst: 'Ueber den Bergbau im Laurion.' *Jahrb.* d. k. k. Bergak., Vienna, 1902, pp. 447-501. H. F. Collins: 'The Mines of Laurium, Greece,' *The Engineering and Mining Journal*, November 10, 1904, p. 751.

Both the crystalline rock and the overlying Cretaceous strata are, according to Lepsius, "bent up in the mountain land of Laurium into an anticlinal fold, whose axis runs straight through the whole mining field from the south coast at Legrana north-northeast, across Camaresa, the Rimbari mountain range, and across the pass of Plaka as far as the northeast coast toward Daskalio-Niki; the main ore deposits and the Plaka granite stock occur in the anticline." The strata of the east flank of this anticline dip very regularly and at a low angle to the east-southeast, while the west limb has undergone disturbance. In the deep workings below Camaresa, in the Serpieri and Hilarion shafts, the strata of this west flank dip west-northwest of 50°.

Important ore deposits are found in a bed of marble, intercalated below the lower horizon of the Kaesariani schists, and wedging out westward.

According to A. Cordella, the ore deposits consist (1) of true veins, (2) of irregular, often bed-like stocks.

The veins were worked by the ancient Greeks in the Camaresa and Sinterni valleys. They occur in both the mica schist and marble, strike approximately parallel to the anticlinal axis, previously noted, and dip west at 70° to 80°. The vein filling, parts of which may still be seen, consists of argentiferous galena, pyrite and chalcopyrite, zinc-blende, fluorspar, calcspar, quartz, yellow vein clay and some secondary minerals. The veins are thin.

The main mass of the ore occurs as stock-shaped deposits along the contact between marble and schist, extending into the former in separate bodies or shoots. Three contacts are distinguished:

1. Upper	Athenian Cretaceous slate. Lower Cretaceous limestone (iron limestone).
2 Second	Upper marble. Kaesariani mica schist.
3. Lower	Kaesariani mica schist. Lower marble.

The marble bed of the mining district, intercalated in the lower horizon of the mica schists, also carries masses of ore along its contact.

The ore of the different contacts is not uniform. The uppermost consists mainly of manganiferous brown hematite with but very little argentiferous galena and without zinc ores. The second and third contacts consist mainly of zinc-blende and the oxidized ores formed from it, together with argentiferous galena, cerussite, oxidized copper ores, pyrite, red hematite, spathic iron ore, calcspar, quartz and at times also fluorspar. They are therefore similar to the veins in composition. The irregular contact ore-bodies send out stringers, and at times upright stocks, whose arms tapering

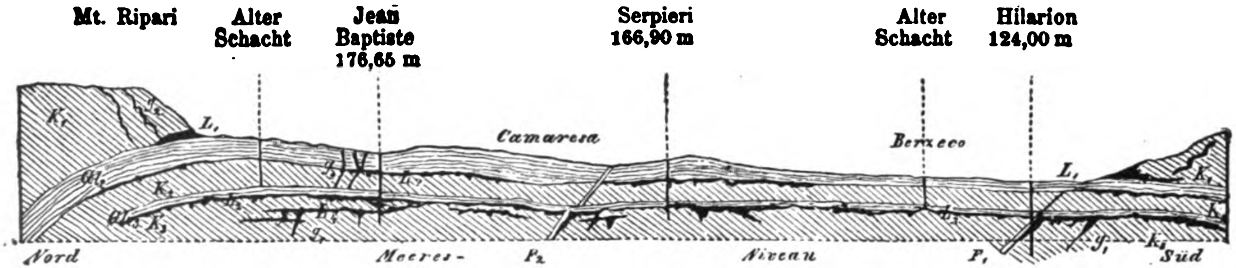


Fig. 220.—Cross-section through the most important lead and zinc deposits of Laurium, Greece. Scale 1: 15,000.

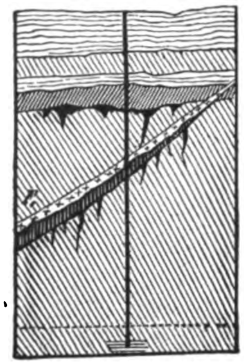


Fig. 221.—Section through the Hilarion shaft, 130 meters deep, 124 m. above the sea. Gl_2, mica schist, 18.5 m.; K_2, limestone, 9 m.; Gl_3, schist, 1.5 m.; L_3, lead ore-bed, 5 m.; m, zinc ores of floor of bed. Base of crystalline limestone, 96 m., with a felsite dike, 1 m., and a zinc vein 2.5 m. in footwall. Dotted line shows sea level; groundwater at bottom of shaft.

Fig. 222.—Section through the Jean Baptiste shaft, 176.6 m. above sea level, and 112 m. deep. Gl_2, mica schist, 44 m., with lead veins, g_2; *a*, old workings of 26 m. level; L_2, lead ore-bed, 0.5 m.; K_2, limestone, 31.6 m.; Gl_3, mica schist, 1.4 m.; L_3, third contact, lead ore-bed; L_4, zinc ore, 3.5 m.; K_3, marble.

downward, penetrate into the lower marble, as appears from the sections Fig. 221 and 222, which are copied from Cordella's work.

There can hardly be any doubt that the orebodies found in the Laurium rocks are due to an invasion by ore-depositing waters from below. As the deposits are richest near the Plaka granite mass, the genesis of the ores is, according to Lepsius and others, connected with the intrusion of that granite. The deposition of the ores is mainly the result of a metasomatic replacement of the marble, especially at points where the impervious overlying slate caused the solutions to stagnate, as a result of which ores replaced the calcium carbonate mainly along the boundary between the two rocks. The zinc sulphide was afterward altered by surface agencies into calamine, etc.

The mines worked by the ancient Athenians were mainly located in the vicinity of Ergastiria and Thoriko (Porto Mandri), where some 2,000 shafts averaging 250 feet deep have been found. Enormous accumulations of old lead slag and extensive old dumps (*ekvolades*) bear witness to the vastness of the ancient work. The ancient mining town of Thoriko existed even in Theseus' time and was fortified in the twenty-fourth year of the Peloponnesian war. According to a legend, the Laurium ores were known as early as the heroic age. According to this myth the gold was discovered by Helis, a son of Ozeans, the silver by Erichthonius, a son of Vulcan. According to Cordella, the ancients produced in the Laurium district in 300 years 2,100,084 tons of crude lead with a silver content of 22,500,000 lb. troy. In recent times the slag and dumps have been re-treated, and, besides the lead ores, the zinc ores, neglected by the Athenians, are also mined. In 1898, Laurium produced 30,650 tons of cadmia ore.

2. *The Silver-Lead Ore Deposits of Eureka, in Nevada.*

The ore deposits of Eureka[1], Nevada, and some other so-called "chamber mines" of America, such as Richmond in Nevada, Emma, Flagstaff and Kessler Cave in Utah, are irregular bodies or stocks of silver-lead ore in limestone. This type of deposit was for some time a prominent topic of discussion, because the deposits were the first accurately described examples in the United States of such irregular ore masses in easily soluble rocks. The deposits also played for a long time a prominent part in mining jurisprudence because they could not be classified under any of the categories

[1] Important papers: R. W. Raymond: 'The Eureka-Richmond case,' *Trans. Am. Inst. Min. Eng.*, 1877, Vol. VI. p. 371. J. S. Newberry: 'The Origin and Classification of Ore Deposits,' School of Mines *Quarterly*, March, 1880. New York. J. S. Curtis: 'Silver-Lead Ore Deposits of Eureka,' *Monog.* VII, U. S. Geolog. Survey, 1884. A. Hague: 'Geology of the Eureka District,' *Monog.* XX, 1892.

provided in the mining laws, being neither lodes nor beds proper, and hence gave rise to many legal contests. Their geologic genesis also led to controversies, which have been of great benefit to science. Newberry regarded them as examples of genuine cavity fillings, the cavities, according to him, having been leached out by atmospheric water charged with carbon dioxide, while the filling with ore was accomplished by rising solutions. He based this view largely on the fact that the limestone of the walls of the ore-bearing chambers showed no impregnation with ore, and on the further fact that empty cavities still occurred in these districts. Later on, however, the view advocated by J. S. Curtis gained acceptance. According to him the ore was deposited by metasomatic replacement, not by cavity filling, and it was deposited by uprising solutions. The empty cavities have been shown to be due to subsequent alteration by descending surface waters.

All of these investigations were carried on in the region about Eureka, Nevada. The country rock there consists of 30,000 feet of Paleozoic strata of varied character and different ages; quartzites, limestones and slates of the Cambrian; limestones and quartzites of the Silurian; limestones and slates of the Devonian; quartzites, limestones and conglomerates of the Carboniferous. The ore deposits occur in Cambrian limestone, which has been crushed and shattered in a broad fault zone which was a channel for ore-bearing solutions. The ore formed well defined but irregular stock-shaped or tube-shaped bodies, the largest of which was followed to a distance of 400 m. (1,312 ft.) The primary ore was a rich argentiferous galena, oxidized in the upper portions to cerussite and anglesite, as well as horn-silver ores. The ores held a slight amount of gold.

3. *The Lead and Zinc Ore Deposits of Monteponi*[1].

In the Iglesias district in the mountainous southwest part of the island of Sardinia, the Silurian limestone contains extensive deposits of zinciferous galena ores and their oxidation products, that were formerly worked by the Carthagenians and the Romans. The Monteponi mine, near Iglesias, is the most important of the numerous mines. The ores occur in great columns or ore shoots over 100 m. (328 ft.) in height, 60 of which are worked. They mostly occur at the contact of clayey limestone with dolomites.

[1] Most important publications: G. Zoppi: 'Descrizione geologico-mineraria dell' Iglesiente.' Sardegna, 1888. Marx: 'Geogn. u. bergm. Mittheilungen über den Bergbaubezirk von Iglesias auf Sardinien.' Z. f. d. B.-, H.- u. S.-W. i. preuss, St. 40, 1892, pp. 263-278. Fuchs and de Launay: 'Traité des Gîtes Minéraux et Métallifères,' Vol. II, 1893, pp. 387-411. 'Carta Geologico-Mineraria dell Iglesiente,' Rome, 1888. Also, 'Carta Geol.-Miner. del Sarrabus,' Rome, 1889.

Two groups may be distinguished: a southern consisting of chimneys of galena ore, and a northern, consisting mainly of oxidized zinc ores.

The galena orebodies also contain some blende and pyrite. Calcite and dolomite spar sometimes associated with quartz form the mostly gray and breccia-like gangue (as at Livello Sella and Scavo Genieguas), also with white, foliated barite (as at Albusini). A zone of yellow ochrous clay is usually found between the ore masses and the limestone. On the contrary, where the galena directly adjoins the limestone, druses are encountered, with magnificent crystals of cerussite, anglesite and phosgenite. Cerussite is often seen with angular remnants of undecomposed galena.

In the immediate vicinity of the stocks of oxidized or cadmia ores the limestone has been altered to a fine-grained, crystalline, gray or yellowish, oftentimes foliated dolomite. The cadmia consists mainly of smithsonite colored yellowish or reddish by iron oxide, often in reniform-botryoid, fine-layered forms, black-brown on the surface, with a varnished appearance. Dolomite breccias are also found, cemented by smithsonite. Alongside of these occurs hydrosilicate of zinc (calamine), in cavernous masses, whose cavities are studded with colorless transparent crystals. Mention must also be made of the occurrence in this cadmia zone of cavities containing brown-yellow or brick-red crusts and efflorescent fillings. Fissures are also found, filled from above, with a breccia of schist and lignite fragments cemented by calcite (as in the Dislocazione Monsignore, Livello Mare).

The only eruptive rock known is a diabase dike 40 m. thick, on the road to Genieguas. At some distance from that point vein-like deposits are known, occurring in part in the granite, such as the lode series of Montevecchio, close to the contact of the Silurian slates with the granite at the high plateau of Arbus, carrying pyritous-blendic lead ore.

4. *The Zinc and Lead Deposits of the Mississippi Valley.*

The lead and zinc deposits of the Mississippi Valley are of exceedingly great economic and scientific interest, and have been carefully studied and described by various scientific observers[1]. The rocks are limestones of

[1] Important literature: J. D. Whitney: 'The Metallic Wealth of the U. S.,' 1854, pp. 403-417. 'On the occurrence of bones and teeth in the lead-bearing crevices,' Amer. Assoc. Adv. Sc., 1859. *Rep.* of the Geolog. Survey of Iowa, 1855-'57. 'Geology of Iowa,' 1858, Vol. I, part 1, pp. 286-295, 422-471. *Rep.* of a Geol. Survey of the Upper Mississippi Lead Region, Albany, 1862. A. Schmidt: 'Forms and Origin of the Lead and Zinc Dep. of Southwest Missouri,' *Trans.* St. Louis Acad. of Sc., Vol. III, p. 246. 'Die Blei- und Zinkerzlagerst. von Südwest-Missouri,' Heidelberg, 1876. A. Winslow: 'Lead and Zinc Dep. of Missouri,' *Trans.* Am. Inst. Min. Eng., Vol. XXIV, pp. 634-931. 'Lead and Zinc Dep.,' Missouri Geol. Survey, 1894, Vol. VII, p. 645. T. C. Chamberlin: 'Wisconsin Geol. Survey,' 1882, Vol. IV, pp. 451-482. W. P. Blake: 'Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Am. Inst. Min. Eng., 1894, Vol. XXII, pp. 629-632. 'Wisconsin Lead and

Silurian age over most of the region, but a part are Lower Carboniferous beds. For the present purpose they will be treated as a unit.

The deposits occur in the following districts: (1) The Upper Mississippi Valley, including southwestern Wisconsin, eastern Iowa and northwestern Illinois; (2) central Missouri; (3) the Missouri-Kansas area; (4) southeast Missouri; (5) northern Arkansas; (6) southern Illinois and Kentucky; (7) southern Arkansas.

Of these regions, (2) and (3) belong within the area of the Ozark arch, (5) to the Ouachita Mountains, separated from the preceding by the Arkansas Valley. Within the confines of these two anticlinal swells, the ore-bearing strata are gently inclined; elsewhere their dip is still less. No eruptive masses occur anywhere.

In the *Upper Mississippi Valley* the ores are confined to the Silurian, which is here classified as follows from above downward:

Cincinnati shale, 200 ft.

Galena limestone, 450 ft.

Oil-bearing shale, 2 ft. to 3 ft.

Trenton limestone, 40 ft. to 100 ft. (contains layers of shale, especially at the base).

Greenish-blue clay, 1 to 2 ft.

St. Peter's sandstone, 50 to 150 ft.

Lower Magnesian limestone, 100 to 250 ft.

Potsdam sandstone, 700 to 800 ft.

Precambrian.

The ores are found partly in 'gash veins' or vertical clefts (Fig. 224); partly in enlarged joints between strata, the so-called 'flats,' and as fillings of quite irregular rents (Fig. 223), finally also as impregnations of certain beds. They are always associated with zones of fracture. They are especially frequent in the flat synclinal depressions of the terrane, in the synclines of the folds striking east and west. The main strike of the fissures

Zinc Dep.' *Bull.* Geol. Soc. Am., Vol. V, 1894, p. 28. W. P. Jenney: 'The Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Am. Inst. Min. Eng., 1893, Vol. XXII, pp. 171, 621. F. Posepny: 'Genesis der Erzlagerst.,' Freiberg, 1893, p. 157. S. F. Emmons: 'Fluorspar deposits of Southern Illinois,' *Trans.* Am. Inst. Min. Eng., 1893, Vol. XXI, pp. 31-51. J. D. Robertson: 'Missouri Lead and Zinc Dep.' Am. Geol., 1895, p. 235. A. G. Leonard: 'Lead and Zinc Dep. of Iowa,' Iowa Geol. Surv., 1897. J. F. Kemp: 'Ore Deposits of the U. S. and Canada,' 1900, p. 240 (gives literature). J. C. Branner: 'The Zinc and Lead Region of North Arkansas,' *Ann. Rep.* of the Geol. Surv. of Arkansas, 1900, Vol. V. S. Calvin and H. F. Bain, 'Geol. of Dubuque County,' *Ann. Rep.* of the Iowa Geol. Surv., 1900, Vol. X. W. E. Burk: 'The Fluorspar Mines of Western Kentucky and Southern Illinois,' 'The Mineral Industry,' 1901, Vol. IX, pp. 293-295. C. R. Van Hise and H. F. Bain: 'Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Inst. Min. Eng., London, 1902, pp. 1-60. *Idem:* 'Lead and Zinc Deposits of the Ozark Region,' 22d *Ann. Rep.* U. S. Geol. Survey, part II, 1902, pp. 31-225. G. I. Adams: 'Zinc and Lead Deposits of Northern Arkansas,' U. S. Geol. Survey, 1904. Prof. paper No. 24.

also follows this strike. The ore is found mainly in the Galena limestone. This, as well as the Trenton limestone, is very rich in organic matter.

Above ground-water level, the ores consist mainly of galena and smithsonite with calcite as a gangue. At a lower level, zinc-blende and marcasite occur, galena is rare, and pyrite and copper pyrite are subordinate accessories. Still farther down, the marcasite gradually displaces the other ores. In genetic succession, in the upper levels, galena is always the youngest ore, for its crystals coat the druses. The deposition of galena took place in geologically very recent time, and in this case it was due to descending solutions. In fact, fissures have been found that widened into chimneys

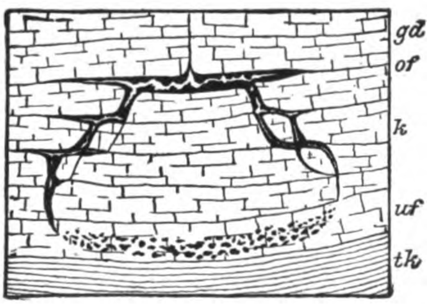


Fig. 223.—Ideal section of a Wisconsin lead deposit. (Chamberlin.)
gd, Galena dolomite; tk, Trenton limestone; of, upper flat; uf, lower flat; k, ore-bearing fissure.

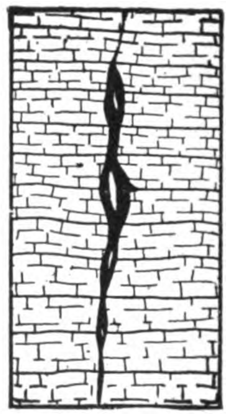


Fig. 224. — Enlarged fissure filled by galena. (Chamberlin.)

containing stalactites of galena pendant from the roof, and in fissures close to the outcrop teeth and bones of Pleistocene mammals were found that were cemented by coarsely crystalline galena.

The *Missouri-Kansas area* is not only the best known but the most important and includes the important mining towns of Joplin, Missouri, and Galena, Kansas. This region lies on the west slope of the Ozark arch. Over this wide extent of country the ores are confined to certain areas, separated by barren zones.

The ores of this field occur in the Cherokee, Mississippian (Boone or Keokuk) limestone of Lower Carboniferous age, containing beds of chert; above this, when not removed by denudation, are the sandstones and shales of the Upper Carboniferous coal measures. The ore-bearing formation is everywhere underlain by the Eureka-Kinderhook shales (Devono-Carboniferous), impervious to water. Below these follows the Devonian, Silurian and Cambrian. The orebodies are confined to zones of faulting and folding.

The ores consist mainly of galena and blende, with less amounts of oxidized zinc ores and very little marcasite, pyrite and chalcopyrite. Dolomite is the predominant gangue, though a good deal of calcite, quartz and barite is also found at times. The Joplin district alone produced in 1902 262,545 tons of zinc ore and 31,615 tons of lead ore. The total production of the Missouri-Kansas district to 1899 amounts to 2,176,700 tons of zinc ores and 631,200 tons of lead ores. Above the ground-water level the ores are limited to galena, calamine and various secondary minerals in a red clay.

The limestone in the mineral district has a crystalline texture and is so rich in bitumen in some mines that the dressing of the ores is interfered with. Near the orebodies, the normal limestone is always dolomitized. Perhaps the chert beds have also been formed by a secondary alteration of the limestone, which in that case, however, preceded the secretion of ore, for chert breccias cemented by ore are common. The form of the orebodies is similar to those of the Upper Mississippi Valley.

Conditions in the other districts are similar except that in the *Illinois-Kentucky region* the galena and blende veins found in the Lower Carboniferous limestone carry very much fluorspar in their upper parts. They are in fact mined for that mineral (as in Eagle mine, near Salem, Kentucky). At a greater depth the fluorspar is replaced by calcite. It is also to be noted that in the south Arkansas district the lead and zinc ores occur together with silver, gold and antimony ores in true fissure veins with quartzose gangue.

Concerning the genesis of all these deposits, the most diverse opinions have been advanced. Whitney, Chamberlain and Winslow explain them by assuming that the metals were primary constituents of the limestones and have been leached out by lateral secretion and redeposited by means of the reducing organic material in the rocks. The main support of this opinion lies in numerous analyses by Robertson, who demonstrated minute quantities of zinc and lead in the most diverse Silurian and Carboniferous limestones. Percival, Jenney and Blake, on the contrary, regard the ores as deposits from ascending thermal waters, rising from unknown depths. That the real deposition of ore below ground-water level took place, however, from uprising currents, is also affirmed by Van Hise and Bain. These authors, however, regard the currents not as thermal springs, but as artesian water, of atmospheric origin. From catchment areas, situated at a higher level, it is supposed to have first seeped down, following a porous stratum confined above and below by impervious shales, and passing through the dolomitic limestones of the Silurian, to have leached out the minute amount of metal held by them. Finally reaching the fault fissures of the zone of dislocation, the water is assumed to have risen and redeposited its load in the more bituminous beds. After removal of the upper shale by erosion, a second concentration was produced by descending currents forming the deposits now mined. (See page 378.)

To the present writer, the presence of barytes and fluorite, in fact the entire mineral assemblage of the deposits, so closely resembling that of genuine silver-lead veins of hydrothermal origin, indicates that the hydrothermal theory is the correct one, especially since it will hardly be proved that the zinc and lead contents of the limestones were not themselves introduced by subsequent infiltration.

5. *The Zinc Deposits of Iserlohn, Prussia.*

At Iserlohn in Westphalia, according to L. Hoffmann[1], a series of zinc deposits were found in the Middle Devonian Stringocephalus limestones or 'Massenkalk,' being confined to the horizon immediately above the underlying Lenne shales. The deposits lie in a zone 12 km. (7.2 miles) long, extending from Lethmathe across Iserlohn as far as Deilinghofen. Fifteen separate deposits are known. Their upper boundary against the overlying limestone is generally very irregular. In some cases the masses of ore are stock-like, the thickness of the orebody exceeding the extension along the strike. These orebodies are steeply inclined, parallel to the stratification of the Devonian. The so-called "First Fissure," for example, is only 3 m. in extent along the strike of the strata, but is 25 m. in thickness. Barren limestone strata divide it into several beds, which here and there run together. The lowest of these beds rests directly on the Lenne shales, which dip north about 35°.

The ores consist of calamine, smithsonite, zinc-blende, pyrite, some galena and a limonite gossan. Fragments of unmineralized limestone are found in the midst of the orebodies. They are usually rounded, and up to several meters in diameter, occurring frequently near the boundary of the deposit. The blende is frequently developed in the form of shell blende, at times having a reniform-botryoid surface, and here

[1] Trainer: 'Das Vorkommen des Galmeis im devonischen Kalkstein bei Iserlohn,' *Verh.* d. naturh. Ver. d. preuss. Rheinl. 1860, Vol. XVII, p. 261. Eichhorn: 'Die Zinkerzlagerstätten bei Iserlohn,' *Z.* f. B.-, H.- u. S.-W. im preuss. St. 1888, Vol. XXXVI, pp. 142-149. L. Hoffmann: 'Das Zinkerzvorkommen von Iserlohn,' *Zeit. f. Prak. Geol.*, 1896, pp. 45-53.

and there coated with zincspar rhombohedrons. Thus the origin of the deposits is due partly to the replacement of the limestone, partly to the filling of cavities previously leached out. Almost all the orebodies of this locality, for that matter, extend to but a moderate depth, rapidly wedging out. The greatest depth disclosed by mining in Fissure I is only 205 m. (672 ft.)

In 1894 the Iserlohn mines produced 8,669 tons of cadmia, 4,185 tons of blende and 77 tons of galena, which figures at the same time illustrate the ratio of the quantities of these ores. Here and there pyrite has been extracted (64 tons in 1894).

Closely similar deposits occurring in the Devonian limestone of Bergisch-Gladbach have been described by von Huene[1].

6. *The Ore Deposits Near Aachen*[2] *(Aix-la-Chapelle), Prussia.*

The ore deposits in the vicinity of Aachen, 44 miles west-southwest of Cologne, do not all belong in this group, since true veins occur, as well as irregular replacements. The deposits are, however, discussed as a whole, since they are evidently related.

The geologic map of the Aachen mining district (Fig. 225) shows Devonian and Carboniferous limestones outcropping in parallel northeast-southwest belts. The beds are steeply tilted, folded and faulted by numerous dislocations. Nearly undisturbed Senonian shales cover the older rocks where not removed by erosion. Volcanic rocks are entirely absent. Detailed studies of the district show that the same horizons are repeated as a result of folding, the folds near the Belgian frontier being overturned and at Walhorn Hittfeld and Herbesthal Fossay showing overthrusts. This series of anticlinal folds and intervening syncline is cut across by a number of faults at right angles to the strike of the strata. The most noticeable is the great fault called Münstergewand, which is so important a feature in the neighboring Inde coal basin.

The ore deposits are closely connected with these transverse faults, as is at once seen from the map. Two types of deposits prevail: (1) mineral

[1] v. Huene: 'Das Vork. von Galmei, Blende, Bleierz,' etc., bei Bergisch-Gladbach' Z. d. D. G. G., 1852, Vol. IV, p. 571.

[2] M. Braun: 'Ueber die Galmeilagerstätte des Altenberges im Zusammenhang mit den Erzlagerstätten des Altenberger Grubenfeldes und der Umgegend,' Z. d. D. G. G., 1857, Vol. IX, pp. 354-370. Holzapfel und Siedamgrotzky: 'Berg. und Hüttenm. Excursionskarte in die Umgegend von Aachen,' 1886. H. v. Dechen: 'Orographisch-geognostische Uebersicht von Aachen,' 1866. W. Schiffmann: 'Die geogn. Verh. und die Erzlagerstätten der Grube Diepenlinchen bei Stolberg,' (Rheinl.) Z. f. d. B.-, H.- u. S.-W. im preuss., St. 1888, Vol. XXXVI, pp. 83-122. C. Dantz: 'Der Kohlenkalk in der Umgebung von Aachen,' Z. d. D. G. G., 1893, Vol. XLV, pp. 594-683.

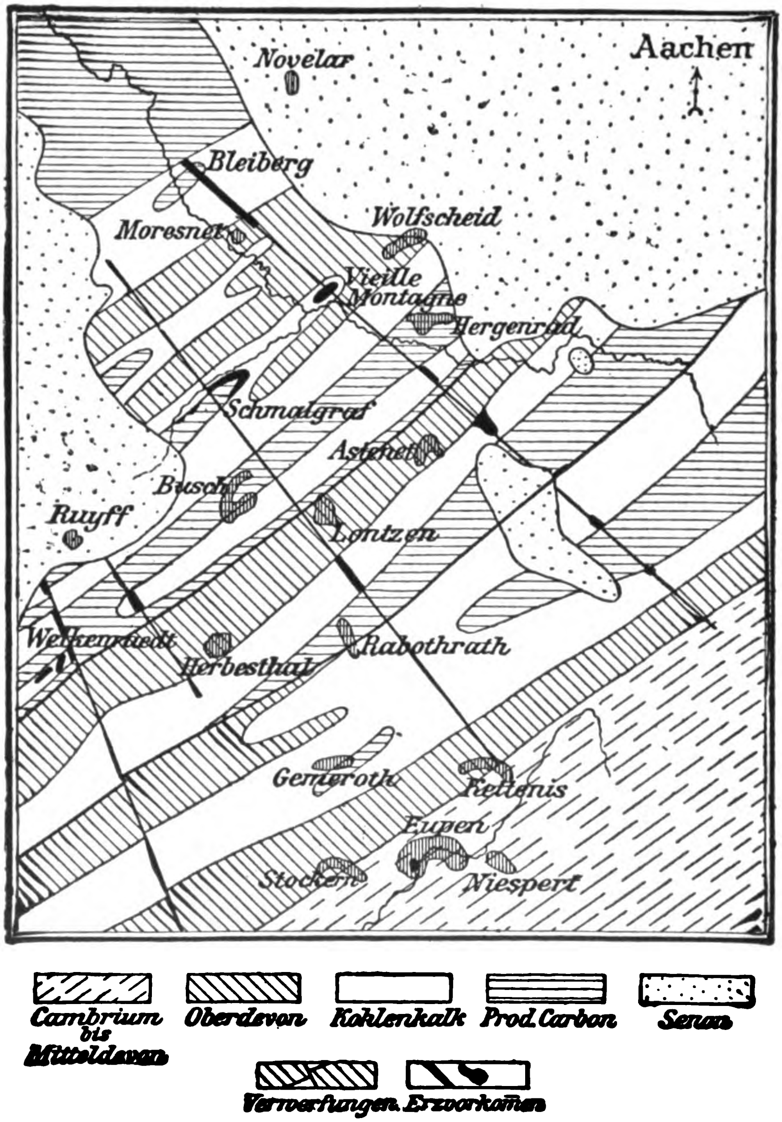


Fig. 225.—Geological sketch map of the mining district southwest of Aachen. (Dantz.) Scale 1: 120,000.

1, Cambrian to Middle Devonian; 2, Upper Devonian; 3, Carboniferous; 4, Coal measures; 5, Senonian; 6, faults; 7, orebodies.

veins; (2) replacements along bedding planes and contacts (pockets, chambers, etc.).

1. The veins all belong to the group of cross faults. In the slates (Upper Devonian) and Coal Measure rocks the fault fractures are very narrow and often scarcely recognizable. They open into broad, large and important veins in the limestones, owing to replacement and solution of the soluble rock by circulating water. These replacements consist of galena and blende with calcite, altered near the outcrop into oxidized ores. The most important lead and zinc veins are those of the Breiniger Berg, near Stolberg, the main vein of this locality passing finally into the great fault (Münstergewand) already mentioned. The ores of these veins show concentric crusts and shells, exactly like those of the irregular deposits near by.

2. The replacement deposits along bedding planes between limestone and shale show a great diversity of form and character.

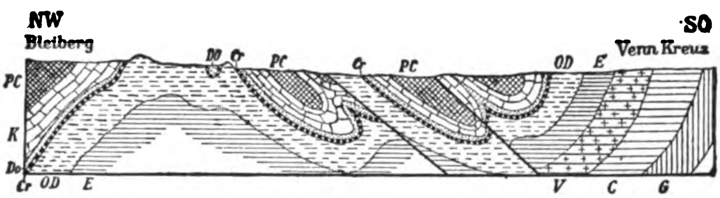


Fig. 226.—Section across the mining district between Bleiberg and Vennkreuz.
IC, productive coal measures; K, limestone; Do, dolomite; Cr, crinoid limestone; OD, Upper Devonian; E, Eifel limestone (Middle Devonian); V, Vichter beds; C, Coblentz beds; G, Gedinnien. (V, C, and G are Lower Devonian.)

Thus the type found in the Diepenlinchen mine near Stolberg has the form of a greatly enlarged vein. This form grades into thick and rounded orebodies called stockworks, that lie in the Carboniferous limestone along the parting between the limestone and shale. Some of these deposits are of very large size. The largest is the 'Brennessel-Stockwork.' This deposit is said by W. Schiffmann to be merely a vein-like mass on the 34-fathom (204 ft.) level, but it increases in size in depth until at the 72-fathom (432 ft.) level it attains a maximum length of 90 m. (295 ft.) and a greatest breadth of 40 m. (131 ft.). There is no sharp boundary between the ore and the enclosing Carboniferous limestone; the ore fades away gradually into the latter. At a few points only does it end sharply against beds of solid limestone. Toward the south the orebody has vein-like spurs, and contains several unmineralized limestone pillars within its mass. The ore of the upper levels consists of calamine, galena, cerussite and some pyrite. The oxidized zinc ore passes into blende below the 49-fathom (294 ft.) level, while the cerussite continues to the 72-fathom level. In the middle of the deposit the ore forms shelly masses in limestone or sandy dolomite, but near the border of the orebody the ore occurs disseminated through it. Calcspar also occurs in fissures and druses. On the 80-fathom level there are no oxidized ores.

In the Heinrich-Stockwerk of the same mine, exactly contrary structural conditions prevail. The orebody is seen to contract from above downward into a series of lode-like occurrences.

But even where the variously shaped and often very irregular stocks and pockets of the Aachen ores do not pass directly into true lodes, as they do here, they almost always, as shown by M. Braun, lie along the lines of intersection of the above mentioned fault fissures with the boundaries between the calcareous and the non-calcareous members of the rock. A glance at the illustration shows this for all the more important deposits of that locality. The orebodies lie at the parting between Upper Devonian and Carboniferous limestone, according to C. Dantz, as seen in the Eschenbroich, Fossey, Altenberg mines (oxidized zinc ores), and those of Poppelsberg and Welkenraedt (blende and galena). Deposits also occur between the Carboniferous limestone and the Coal Measures, as may be seen in the Eschenbroich mine (galena and blende), the Schmalgraf mine (shellblende and galena), Henriette, near Eich (brown hematite), and some cadmia (zinc) stocks of Welkenraedt.

The most famous of all these deposits is that of Altenberg (Vieille Montagne) or Kelmisberg, on the neutral territory of Moresnet, which was exhausted as early as 1844. The cubic contents of this ore stock is estimated by M. Braun at 340,000 cubic meters. According to the same author, it yielded in 500 years about one million tons of cadmia, being worked by open-cut. This vast deposit consisted almost exclusively of cadmia, in which only scattered kidneys and stringers of red clay occurred. It was formed of an intimate mixture of zinc spar and hydrosilicate of zinc, enclosing here and there larger and smaller nodules of willemite. Calamine predominated. In the upper workings druses and large cavities often occurred, with crystals of smithsonite, calamine, iron-zinc spar (capnite), zinc-bearing calcspar, more rarely of quartz. The country rock was for the most part dolomitized Carboniferous limestone, forming a syncline wedged in between Devonian slates.

Besides the stock-shaped and chamber deposits, there are also bed impregnations, usually along a definite strata, and showing an evident genetic connection with the other deposits. A bed of Carboniferous clay slate is impregnated with lead ore and blende for a distance of 2 km. to 2.3 km., according to M. Braun.

In 1898 the district just described (Düren mining district) produced 12,849 tons of blende and 5,830 tons of cadmia, the latter from the Altenberg mines of Schmalgraf, Eschenbroich, Fossey and Mützhagen. At the same time 1,303 tons of lead ore were produced, mainly in the Diepenlinchen mine.

Deposits quite similar to those mentioned are also found in Belgium, near Corphalie, Flône, Engis, and de la Mallune, near Liege, as well as in bedlike deposits near Philippeville. The extent of these occurrences may be gathered from the fact that Belgium in 1897 produced about 11,000 tons of zinc ore.

7. *The Oxidized Zinc Deposits of Picos de Europa, Spain.*

Deposits of "cadmia" similar to those of Aachen occur in Carboniferous limestones of the eastern half of the Picos de Europa in the districts of Andara and Aliva, in northern Spain[1]. Fine stalactitic masses of white, dense cadmia are extracted from cave-like enlargements of the deposits of that locality, and the ores are still forming, as shown by crusts on old tools. Here, too, the calamine stocks are associated with zones of fissuring and are probably a secondary alteration product of blende, as is proved by nodules of undecomposed blende found in them. An unusual feature is the accessory occurrence of cinnabar in these deposits.

8. *Lead Deposits in the Carboniferous Limestone, England.*

An extensive district of lead deposits occurs in the area of Carboniferous limestone rocks of Derbyshire[2]. The Carboniferous series, aggregating about 450 m. (1,476 ft.) thick, consists of the following subdivisions:

9. Millstone-grit (barren sandstone) overlying.
8. Shales of the Carboniferous limestone.
7. Limestone with thin layers of shale, 45 m. (147 ft.).
6. Bed of melaphyre (toadstone).
5. Dolomitic limestone with cavities, 45 m. (147 ft.).
4. Toadstone.
3. Limestone with layers of shale, 64 m. (210 ft.).
2. Toadstone.
1. Limestone with layers of shale, over 76 m. (249 ft.).

[1] W. Köhler: 'Die Steinkohlenformation in Nord-Spanien,' *Berg. u. Hütten Zeit.*, 1877, p. 217.

[2] B. v. Cotta: 'Erzlagerstätten,' 1861, Vol. II, pp. 494-498. Note older works of Brochant de Villiers, Dufrénoy, E. de Beaumont and De la Bêche.

The three layers of trap rock (toadstone) intercalated in the Carboniferous limestones are intrusive sills, in part of very considerable horizontal extent. The slightly inclined strata are traversed by genuine lead veins (rakes, rake-veins), which, however, almost without exception are ore-bearing only within the limestones, while in the millstone-grit and in the toadstone they grow barren and sometimes are difficult to trace at all. They are true fault fissures with slickensides and mutual displacements of moderate throw. Most of them strike east-northeast, being parallel to one another. Their filling sometimes shows a regular symmetric arrangement, with crusts of galena, fluorspar, calcspar and barite, more rarely also of quartz, pyrites and blende. Besides this, however, the limestone contains flat layers (flats) or tubular lodes (pipe-veins), that is to say, irregular ore tubes along the intersections of the veins with the joints between the strata. It was the latter fact that caused the ore deposits to be introduced in the present category. Finally, the ores are also found scattered over the cross fractures of the limestone beds (skrins). The district is a classic one in English geology, owing to the writings of De la Bêche.

Similar conditions prevail in the lead fields in the Carboniferous limestone rocks of the extreme north of England, in Northumberland, Durham, Cumberland and Westmoreland, though in these districts vein mining predominates far more over the mining of irregular deposits than is the case in Derbyshire. The most important mines lie at Alston Moore (Cumberland), East and West Allendale (Northumberland), Weardale on upper Wear river and Teesdale (Yorkshire and Westmoreland). The general section differs from that of the Derbyshire district in showing but one intrusive bed of melaphyre, the so-called Whin Sill, intercalated in the Carboniferous limestone. The lead veins have been divided into groups according to their strike: "rake veins" or "right-running veins," striking approximately east and west, "cross veins," striking north and south, and the narrow "quarter-point veins" with intermediate strike. Another peculiar feature is the occurrence of "flats," that is to say, flat, stock-like masses or sheets of ore lying parallel to the stratification. These ore masses are often connected with the veins by means of side fissures ("leaders"). The ore and gangue minerals consist of pyrite, sphalerite, galena, quartz, calcspar, fluorspar and barite. The galena is argentiferous. In 1894, according to H. Louis, the production was as follows:

	Lead ore.	Zinc ore.
Northumberland	1,042 tons.	10 tons
Durham	9,214 "	—
Cumberland	1,750 "	7,228 "
Westmoreland	1,461 "	—

9. *The Silver-Lead Deposits of Leadville, Colorado*[1].

Leadville, Colorado, lies in an upland valley of the Rocky Mountains, traversed by the main tributary of the Arkansas river. This longitudinal valley is bounded on the west by the Sawatch range; on the east by the Mosquito range, on whose foothills the town is built. The Mosquito range consists of old crystalline rocks and intensely folded and much faulted Paleozoic strata, with intrusive sheets of porphyry intruded in Cretaceous time between the beds and cutting across them. The mines lie east of Leadville on Fryer, Carbonate and Iron hills. In the town itself a deep shaft was recently sunk, which reached the ore horizon. The orebodies mostly occur within Carboniferous limestone, directly underlying porphy-

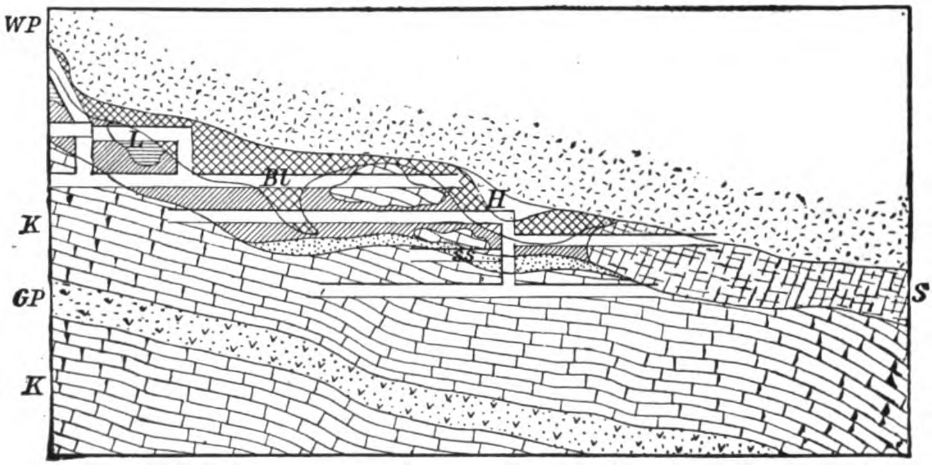


Fig. 227.—Section through the White Cap Orebody of Leadville. (Blow.)
WP, white porphyry; K, limestone; GP. sulphide ore; ss, sandy sulphide ores; Bl, oxidized lead ores; L, clay; H, cavities.

ritic intrusive masses. The few exceptions to this rule, namely, ore-beds within the porphyry, are to all appearance nothing but mineralized or replaced inclusions of the limestone in the eruptive masses. The structural conditions are well illustrated in the section, Fig. 227. The form of the deposits is that of irregular chambers or 'stocks,' in general running parallel to the stratification of the limestone, it is true, but in many cases also

[1] S. F. Emmons: 'Geology and Mining Industry of Leadville,' *Monogr.* XII, U. S. Geol. Survey, 1886. C. H. Rolker: 'The Leadville Ore Deposits,' *Trans.* Amer. Inst. Min. Eng., 1885, Vol. XIV, p. 273. F. T. Freeland: 'The Sulphide Deposits of South Iron Hill,' *Idem*, p. 183. Carl Henrich: 'Origin of the Leadville Deposits,' *The Engineering and Mining Journal*, Dec., 1879, p. 470. Also, May, 1888, p. 43. A. A. Blow: Trans. Am. Inst. Min. Eng., 1889, Vol. XVIII, p. 145. J. F. Kemp: 'Ore Deposits,' 3d edition, 1900, pp. 262-265.

cutting across the limestone beds or enclosing isolated non-mineralized patches of limestone. Sometimes these stocks are so elongated in shape that they have been termed 'pipes.'

The primary ores are sulphides, mainly argentiferous galena, zinc-blende and pyrite, with subordinate amounts of chalcopyrite, etc. The place was first famous for its rich oxidized ores, alteration products of the sulphides, which formed the great orebodies worked for many years. These ores consist of an earthy mixture of carbonates of lead and hornsilver in a clayey or silicious manganiferous brown hematite. The oxidized ores are more or less auriferous. In 1891-1892, in several mines on Breece Hill, situated about two miles east of the town, orebodies were found in the porphyry in which the value of the gold far exceeds that of the silver.

The real nature of these deposits, as a product of replacement, was recognized in the early history of the camp by S. F. Emmons, whose monograph on the district has become almost a text-book for mining geologists. He considered that the ore-bearing solutions derived their metallic contents from the eruptive rocks in the vicinity, and that the main channels of circulation were the contacts of limestone with overlying bodies of porphyry, from which they ate down into the body of the limestone along joints and cracks. Blow, writing later of the sulphide ore of Iron Hill, where it is arranged in longitudinal shoots along fissures in the limestone, thought that the solutions came up directly through these fissures and spread out along the under surface of the porphyry sheets. This view has since been generally accepted as more probable by geologic writers. Emmons had considered the possibility of such an origin, provided the fissures could be found through which the solutions ascended, but claimed that as yet none had been detected. The importance of the eruptive masses lies rather in this, that they dammed back the solutions, causing them to stagnate in the fissures and joints of the adjacent limestone, and to deposit their burden of metallic sulphides by metasomatic replacement.

The silver-lead ore deposits of Leadville were discovered in 1874. The greatest production was in 1880, but the mines are still important producers of gold, silver-lead and recently of zinc ore.

Conditions analogous to those of Leadville also obtain in the silver-lead deposits of Lake Valley[1] in New Mexico, which are stocks and pipes in a Carboniferous limestone at the contact with porphyritic intrusive masses. Lake Valley has yielded many rare minerals, such as vanadinite. The deposits of the Elkhorn mine, Montana, are also of a kindred nature, as shown farther on.

[1] E. Clark: 'The Silver Mines of Lake Valley.' *Trans.* Am. Inst. Min. Eng., Vol. XXIV, pp. 138-167, 1895.

10. *The Silver-Lead Ore Deposits of Aspen, Colorado.*

A recently published monograph by J. E. Spurr[1] has drawn attention to the interesting deposits of Aspen. This town lies on the west side of the continental divide, in the valley of Roaring Fork, close to the boundary between the crystalline schists and the Paleozoic rocks. The strata of the Cambrian, Silurian, Carboniferous and of the Mesozoic formations were here compressed in Cretaceous time into an overfold. The folding was accompanied by overthrust faulting and vertical fault fissures. Where two of these parallel overthrust planes, bringing Leadville limestone under the Weber slates (both formations being Carboniferous), are intersected by a vertical fault, masses of crushed limestone have been replaced by ore. The unaltered ore consists of argentiferous galena with a lesser amount of zincblende and still lesser quantities of pyrite, chalcopyrite, bornite, tetrahedrite, tennantite and in the Smuggler mine polybasite and native silver. The gangues are quartz, dolomite spar, brown spar and barite. The altered ore of secondary origin consists of earthy carbonates and sulphates, especially cerussite and anglesite, together with red and brown hematite.

The gradual replacement of limestone or dolomite by ore is well illustrated in the Aspen district by fossils found in the midst of the ore masses. Such fossils are found not only in the midst of the primary sulphide ores, but also in the masses of silver, probably of secondary origin, where some of the fossils have succeeded in retaining their form. Spurr shows that the ore-forming solutions dolomitized the limestone, with shrinkage of volume.

11. *Ore Deposits in Triassic (Muschelkalk) Limestones of Upper Silesia*[2].

The Muschelkalk[3] of southeastern Silesia forms a flat ridge between one and two miles wide and over ten miles long, extending from Krappitz, on the Oder, as far as Olkusz, in Poland. The beds dip very gently north, while the strike, as far as Siewierz, is east-west, but beyond the Russian boundary turns southeast. A deep gap extending across the middle of the ridge, north of Peiskretscham, divides it into an eastern and a western

[1] J. E. Spurr: 'Geology of the Aspen Mining District, Colorado,' with Atlas, *Monogr.* XXXI, U. S. Geol. Survey, 1898.

[2] Important publications: R. v. Carnall: 'Ueber Eisensteinlagerstätten im Muschelkalk Oberschlesiens,' *Z.* d. D. G. G., 1850, Vol. II, p. 177. v. Krug: 'Ueber die Erzlagerstätten des oberschlesischen Muschelkalkes,' p. 206. H. Eck: 'Ueber die Formation des bunten Sandsteins und des Muschelkalkes in Oberschlesien,' 1865. F. Römer: 'Geologie von Oberschlesien,' 1870. Cappel: 'Ueber die Erzführung der oberschles. Trias nördl. von Tarnowitz,' *Z.* f. d. B.-, H.- u. S.-W. im preuss. St., 1887, Vol. XXXV, p. 99. R. Althaus: 'Die Erzformation des Muschelkalkes in Oberschlesien,' *Jahrb.* d. k. preuss. geol. Landesanst, 1891, Vol. XII. G. Gürich: 'Ueber die Entstehungsw. schles. Erzlagerst.,' *Jahresber.* d. Schl. G. f. vaterl. Cultur. 1902.

[3] Triassic marine limestones above the Bunter and beneath the Keuper formations.

half. Several lateral ridges branch off, one at Tarnowitz running in a southerly direction to beyond Gleiwitz, its eastern prolongation consisting of synclinal troughs of Muschelkalk, with intervening anticlines of Coal Measure rocks. The most important of these synclines are those of Tarno-

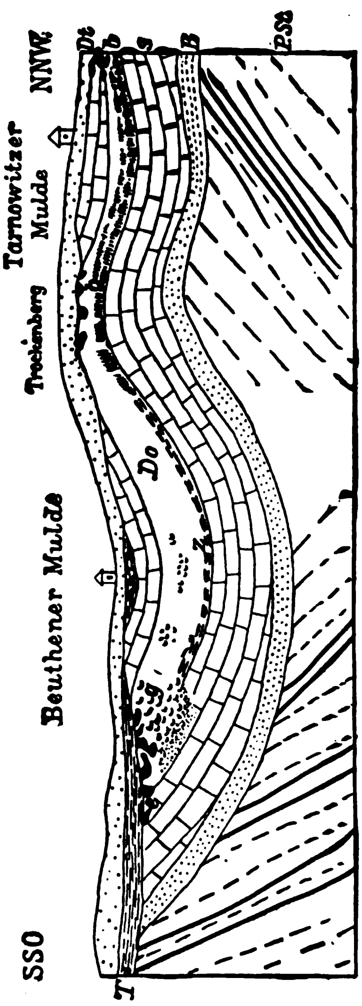


Fig. 228.—Diagrammatic section across the Tarnowitz and Beuthen basins. (Gürich.) P St, productive Coal Measures; B, Bunter sandstone; S, Sohlen limestones (Chorzower bed); Do, dolomite; T, Tertiary; Di, alluvium; b, galena deposits; z, zinc-blende orebodies; g, cadmia bed; e, limonite deposit.

witz and Beuthen, of which a diagrammatic cross section is here given, after Gürich (Fig. 228).

In Upper Silesia (and Poland), as in the rest of Germany, the Muschelkalk forms three divisions, named by Eck:

3. Upper division: Rybna limestone, about 15 m.
2. Middle division: Non-fossiliferous, marly dolomites, about 20 m.
1. Lower division: (a) Cavernous limestone......... } about 200 m.
(b) Chorzow strata.............
(c) Spirifer Mentzeli strata.....

The lead and zinc ores occur only in the lower division. This lowest division is further subdivided by Eck into the following horizons, from above downward:

5. Himmelwitz dolomite.
4. Mikultschütz strata.
3. Encrinite or Terebratella strata.
2. Gorasdze strata.
1. Blue (basal) limestone.

The "cavernous" limestone, the "Chorzow" strata and the basal Blue limestone of the above series of strata are uniformly developed in the eastern and western parts of the plateau. The basal limestone is a dense, clayey limestone, usually of blue-gray color. The Chorzow strata are mostly thinly stratified, either dense or partly crystalline limestones or marly limestone; the Cavernous limestones are non-fossiliferous, crystalline limestones containing numerous drusy cavities.

The three upper divisions of the Spirifer Mentzeli strata differ markedly in character in the two parts of the plateau just mentioned. West of the "gap" they are pure limestones, to the east of it dolomites. As the ores occur only in the *dolomite* this eastern section alone is of economic importance. The ore-bearing dolomite when fresh is a hard, crystalline-granular rock, traversed by a network of fine fissures. Carbonaceous clays are frequently intercalated in the lower beds and almost always occur between the dolomite and the basal limestone. Because they contain pyrite, they are called 'vitriol clays.' The Himmelwitz dolomite with numerous remains of *Nullipora annulata* overlies it.

F. Beyschlag[1] regards the dolomites of Upper Silesia not as normal representatives of definite horizons of the Muschelkalk, but merely as altered limestones, formed along water-bearing fault fissures. The same water that dolomitized the limestone also supplied the ores.

In the deepest parts of the synclines the ores consist essentially of sulphides: zinc-blende, galena and marcasite, the galena predominating in the Tarnowitz syncline, the zinc-blende in the Beuthen syncline. Nearer the outcrop the sulphide is replaced by earthy zinc carbonate and silicate; where galena is present, it shows corroded forms and in cavities is

[1] F. Beyschlag: 'Vortrag über die Erzlagerstätten Oberschlesiens,' *Deutsche Geol. Ges.*, Feb. 5, 1902.

studded with cerussite crystals. Marcasite, the constant associate of the blende, is altered to hematite.

On ascending the flanks of the synclines, the dolomite disappears, and unconsolidated deposits of the marine Miocene make their appearance. Hematite and 'cadmia' occur, however, in pockets in fissures and depressions of the 'basal' or floor limestone. The zinc ores often show pseudomorphs after dolomite (the red calamine) underlain by the white calamine, a replacement of the basal limestone, showing that the mechanical processes of the Miocene sea were accompanied by metasomatic alterations. The deposits, as a whole, form two superimposed more or less continuous sheet-like masses, the upper being less regular than the lower.

Deposits of *lead* ores alone are developed in the Tarnowitz syncline. The upper part consists of a layer of soft ore, a stratum of iron ocher with irregular plates, lumps and grains of galena in the ocher. The "hard ore layer" lies below and is separated from the basal (floor) limestone only by a thin dolomite bed. It consists of a layer of galena about an inch thick, or as stringers, scattered grains and plates in the compact dolomite. Galena is accompanied by marcasite, cerussite, pyromorphite, etc. The galena carries 0.026-0.033% of silver.

Deposits of *zinc-blende* are found on the north flank of the Beuthen syncline, changing to red calamine, as the outcrop of the horizon is approached and finally changing to white calamine near the croppings.

The blende deposit, in the Cäcile and Neue Helene mines, is rarely more than 2 m. thick, while in the fields of the Blei-Scharley mines it attains a thickness of as high as 12 m. The blende, which is in part a 'shell blende' or occurs in stalactitic forms, is accompanied by galena and marcasite. The galena, however, contains only about 1/10 of the silver content of the lead ore deposits proper (*i. e.*, deposits of lead only, not mixed ores).

The upper calamine deposit has been extensively worked, especially in the Neue Viktoria, Paul Richard, Neuhof and Rudolf mines. In these workings it is about 1 m. thick, but the thickness increases southward to 10 m. It commonly contains 0.1-0.113% of argentiferous galena. Where the two layers of calamine unite at the outcrop, the combined thickness is sometimes 20 m. Thus they have been worked in the Scharley, Wilhelmine and other mines. Underlying them, the white zinc ore was often seen extending in deep fissures and cavities in the basal limestone: Compare the section through the Judith and Scharley mines in Fig. 229. There is much similarity between this and other deposits of white zinc ore found over a great part of the area underlain by older Muschelkalk. They, too, occur in part in fissure-like cavities, or lie in trough-shaped depressions in the limestone, as for example in the Matthias mine. Alongside of these, however, sheeted white cadmia deposits have been observed.

The *iron ore* deposits consist mainly of brown hematite, the most important deposits being found on the edges of the dolomite synclines, as at

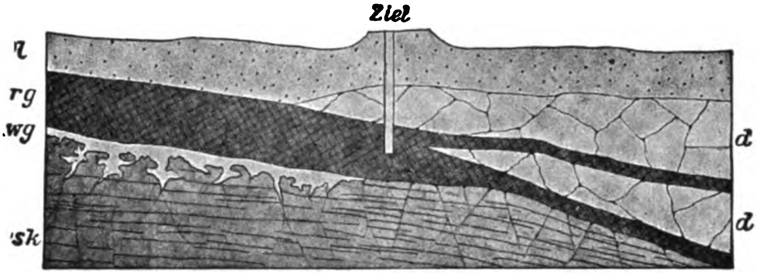


Fig. 229.—Section through the Judith and Scharley mines. (F. Römer.)
l, clay; d, dolomite; sk, basal limestone; wg, white cadmia; rg, red cadmia.

Buchatz and those north of Bobrek and south of Beuthen. The earthy brown hematite often contains some zinc carbonate, lead sulphide and white lead ore. It is banded, but forms irregular, pockety beds of varying thickness, sometimes as high as 20 m. A second mode of occurrence is in fissures and cavities of the basal limestone and of the Chorzow limestone. The brown hematite of these latter deposits often carries calamine ores. It is developed as 'Glaskopf' (radial-fibrous and concentric-shelled, as in limonite and fibrous red hematite) or in stalactites, and is sometimes distinguished by a high manganese content. As an example of the occurrence of the iron ore we give, in Fig. 230, after Römer, a section through the Bally-Castle mine.

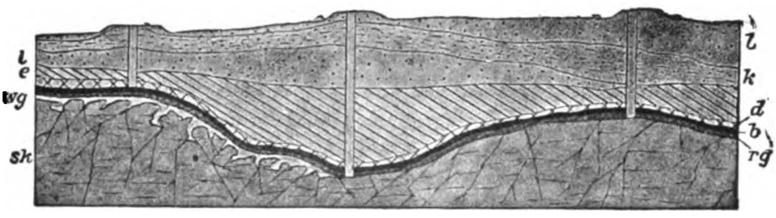


Fig. 230.—Section through the Bally-Castle mine. (F. Römer.)
l, clay; k, Krusawka; e, iron ore; d, dolomite; b, lead ore; rg, red cadmia; wg, white cadmia; sk, basal limestone.

The mining history of upper Silesia extends back to the 13th century. At that time the argentiferous lead ores in the upper-bearing horizon of the Beuthen syncline were worked, while zinc mining began only in the 16th century.

In 1898, the total output of lead in the mining district of Breslau was 40,402 tons, distributed thus: Neue Helene mine, 12,676 tons; Jenny-Otto mine, 5,043 tons; Cäcile, 4,642 tons, and Blei-Scharley, 4,406 tons. The total output of zinc ore in that year was 522,839 tons, of which 219,536 tons or 41.99% were oxidized ore and 303,303 tons or 58.01% blende. The above-named mines, together with the Samuelsglück, are the most important. Upper Silesia contributed almost 2/3 of the total zinc production of Germany.

12. *The Zinc Deposits of Wiesloch near Heidelberg, Baden.*

The Wiesloch zinc deposits are in North Baden about 12 km. (7 miles) south of Heidelberg. The deposits are in strong contrast to those of Upper Silesia, just described, being, according to Schmidt[1], largely due to cavity filling, though accompanied by extensive replacement as well.

The ores occur in fossiliferous marine limestones (Muschelkalk) that overlie red sandstones. This limestone consists of three divisions, the upper or true Muschelkalk contains no workable zinc deposits, the middle is a gypsiferous and salt-bearing series; the lower limestone (Wellinkalk) contains the valuable deposits in its lowest formation, the Trochite limestone.

The deposits are now of no economic importance, but their great scientific interest warrants a detailed description. Zinc mines exist at two points north and northeast of the town. The ore-bearing bed of the limestone is 3 to 6 m. (10 to 20 ft.) thick, resting on marls and limestones and overlaid by three thin (0.15 m.) limestone layers (Blättchen), replaced here and there by calamine ores.

Of the five deposits existing at Wiesloch, whose form may in general be described as that of recumbent stocks with north-south longitudinal extension, the three western ones whose ores are oxidized form the Hesselfeld, while the two others, situated east of the Nussloch fault fissure (which in addition to cadmia also contain blende), compose the Baierthal field. The largest of these deposits is 1,968 feet (600 m.) in length and 984 feet (300 m.) in breadth. However, none of the deposits are compact orebodies, but consist mainly of limestone with numerous pockets, connected by ore-filled clefts and joints between strata. The ore deposits occur arranged in lines parallel to the stratification of the limestone, the bunches often coalescing into large masses. These larger masses always occur along the joints between the strata and occasionally jump from a higher to a lower stratum, along a fissure.

[1] A. Schmidt: 'Die Zinkerzlagerstätten von Wiesloch' (Baden). Heidelberg, 1883. Gives a bibliography.

Besides the calamine ores, with occasional masses of blende, red clays and an argillaceous silicious iron ore also take part in the composition of these ore masses. The richest and hardest calamine ores are mostly reddish, rarely gray in color, and always lie at the lowest horizon.

Numerous vertical fissures occur connected with the pockets and trains of ore nodules. In rare cases, the fissures contain only clay, more frequently iron and zinc ore, or they are filled with zinciferous limonite, red and brown cadmia (smithsonite ores).

The Blendestock deposit of the Baierthal zinc district, unlike all the deposits mentioned, consists in its southern part almost solely of iron pyrite and zinc-blende, the latter in the form of shelly blende, that is to say, with thin intercalations of galena and pyrite. It is to be noted that these blende-carrying patches of ore lie mostly below ground-water level.

As the blende is everywhere readily detached from the country rock, and as its stratiform structure points to uninterrupted formation, and moreover as it occurs in great stalactites, up to 15 cm. thick, and not rarely 30-40 cm. long, A. Schmidt has no doubt that it and the other sulphuretted ores fil! pre-existing cavities. That the solutions in question came from above, as assumed by him, may not be generally admitted. According to the same author the masses of cadmia gained the space they now occupy mainly by a metasomatic replacement of the limestone. This is actually proved by the fossils transformed into cadmia, for example by the completely mineralized specimens, yet recognizable in all details, of *Terebratula vulgaris, Lima striata, Enerinus, Lilliformis,* etc. The entire cadmia (exclusively smithsonite) of the Wiesloch deposits is, according to Schmidt, secondary and formed by the decomposition of blende, with diverse migrations of the resulting solutions.

The Wiesloch mining industry is very ancient. It was carried on as early as the time of Charlemagne, when the silver-lead ores were worked. Zinc mining began in 1846. The Hesselfield now produces about 200 tons of calamine ore per year.

13. *The Lead and Zinc Deposits of Raibl in Carinthia, Austria.*

These deposits occur in an east-west alpine range of Triassic limestone. Raibl lies southwest of Villach and south of the Gail valley in the basin of the Seebach (Schlitz), whose sources are on Italian territory. The heights all around the place rise up to about 1900 m. The ore deposits occur in limestones and dolomites beneath a series of fossiliferous shales, carrying fish remains of Middle Triassic age.[1]

[1] E. Kayser: 'Geol. Formationskunde,' 1902, 2d ed., p. 319.

According to F. Posepny[1] and the official monograph on Raibl,[2] by W. Göbl, the limestones are cut by fault fissures, usually mere partings between polished walls in close contact. These north-south fissures show a displacement of as much as 60 m. (196 ft.), the faults being characterized by brightly polished slickensides, and by partial bending over of the adjoining ends of the strata. They are recognizable even at the

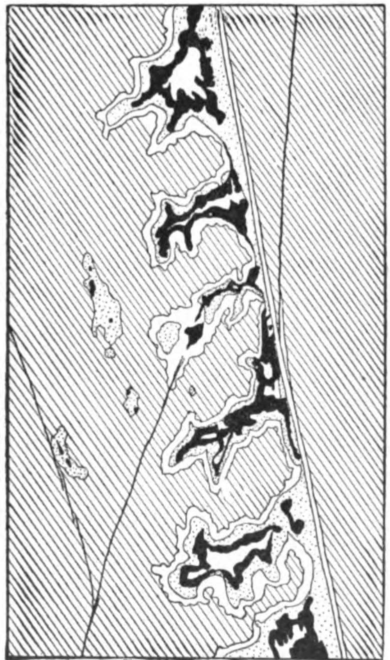


Fig. 231.—Ore deposit of the Josefi-Blatt, near Nordfeldort, Aloisi adit. (Posepny.) d, dolomite; z, sphalerite; b, galena; sp, magnesian spar.

surface, as the deeply cut erosion gorges or "Klamme" have followed their course.

These fault seams do not carry any ore, while the readily soluble dolomite and limestone contain orebodies, especially along the bedding planes between the fossiliferous slates and the overlying strata.

There are two separate fields in the district. In the first, deposits of zinc-blende and galena occur in dolomite rocks with oxidized ores in the

[1] F. Posepny: 'Die Blei- und Galmei-Erzlagerstätten von Raibl in Kärnthen,' *Jahrb.* d. k. k. geol. Reichsanst., 1873, Vol. XXIII, pp. 317-420.

[2] 'Geol.-Bergm.-Karten mit Profilen von Raibl nebst Bildern von den Blei- und Zink-Lagerstätten in Raibl,' Vienna, 1903, with full bibliography.

uppermost horizon. In the second, calamine without blende and but little galena occurs in limestone.

The sulphide deposits of the first area, according to F. Posepny, distinctly betray their character as cavity fillings. Their dimensions and

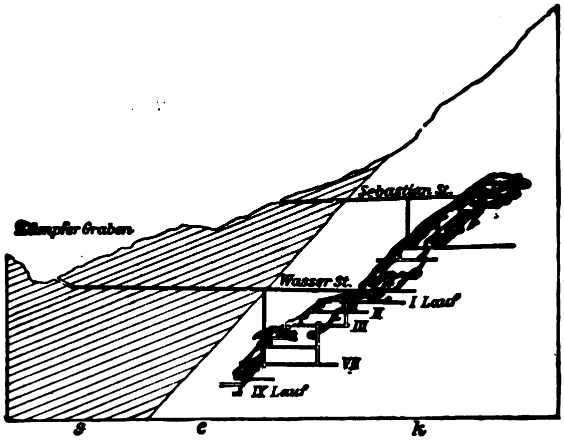


Fig. 232.—Section of the Johanni Clam orebody, north-south section. (Posepny.) s, shale; k, ore-bearing limestone; e, orebodies.

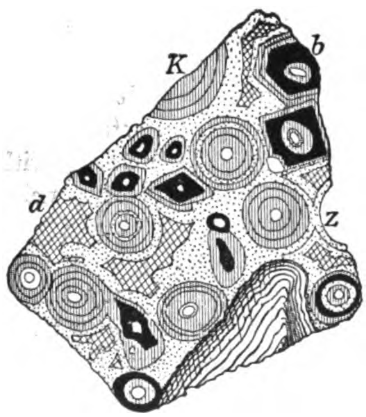


Fig. 233.—Tubular ore from Raibl. (Posepny.) b, galena; z, sphalerite; k, pyrite; d, dolomite spar.

Fig. 234. — Tube-shaped aggregate of galena crystals from Raibl. (Posepny.)

shape are exceedingly irregular, but their whole position and arrangement show such a dependence on the fault seams that both the corrosion of the cavities and their subsequent filling must have proceeded from these fissures. Fig. 231 shows this dependence, and Fig. 232 shows the arrangement of the deposits on a large scale.

Three systems of fissures in particular come under consideration: (1) The Abend- und Morgenblatt, together with the Johanniblatt. (2) The fissure system of the Struggl ores series. (3) The fissure system Vincenzi-Aloisi-Josefi. They succeed one another in an east-west direction. The first three meet at an angle of about 33° and form the boundaries of ore-bodies that extend downward along the fissures.

The orebodies occur in columnar shoots which overlap on the north as the depth increases. The most important sulphide orebody is the main ore shoot between the Abend- und Morgenblatt. It forms a plate 50-140 m. (164-489 ft.) long in the strike and 30-70 m. (98-229 ft.) thick, dipping at 45°, parallel in its strike to the strike of the fissures, contiguous to them, and very irregular. This train of ore masses is at present exposed to a vertical depth of 450 m. (1478 ft.).

These sulphide orebodies consist of banded zinc-blende in very thin crusts (schalenblende), of non-argentiferous coarsely crystalline galena, with some iron pyrite and dolomite in concentric crust-shaped deposits, parallel to the walls of the cavities, but not conformable to the stratification. The dolomite, being the youngest mineral, is apt to form the drusy center, often still studded with barite crystals. Calcspar, zinc spar and white lead ore also occur as secondary decomposition products. A filling of pre-existing cavities is probable, particularly for the 'pipe' ores described in great detail by Posepny. They are obtained from the central part of certain orebodies, where granular dolomite predominates as the relatively youngest deposit, for example from the Struggl mines, seventh level. They consist of broken, hollow stalactites or tubes, composed in concentric layers of diverse material, chiefly galena with altered pyrites, blende, also cadmia and cerussite and frequently enclosed in a matrix of dolomite spar. Some of them are tubular aggregates of nothing but galena octahedrons. The cross-section is not always circular, but often quite irregular. The length of the fragments may amount to 10 cm., the diameter to 2 cm. (see Fig. 233 and Fig. 234, after F. Posepny).

In the 'hanging wall orebody' the so-called slate ore sometimes occurs, stratified dolomite with intercalations of blende and galena.

Between the sulphidic orebodies of the Abend- und Morgenblatt and those of the Vincenzi-Aloisi-Josefi-Blatt lie the calamine deposits of the second field. At this place the limestone is directly replaced by calamine, etc., along fissures and without previous formation of cavities, in such a way that unmineralized cores sometimes remained. Occasionally, the detailed structure of the original rock is retained by the calamine, as for instance the cellular structure of the so-called 'Rauchwacke,' which consists of a skeleton of thin smooth cell walls representing the fillings of cracks in the limestone, the limestone being in part dissolved away or left only in separate decomposed splinters. The cell walls have subsequently been changed to calamine and covered by botryoidal clusters of that mineral, while the former cavities have been filled with a zinciferous earthy brown hematite, the so-called 'Moth' (see Fig. 235).

The Raibl cadmia consists mainly of zinc spar (red cadmia), more rarely of zinc bloom (white cadmia); hydrosilicate of zinc occurs but rarely. Towards the outcrop the zinc ores gradually give way to brown hematite.

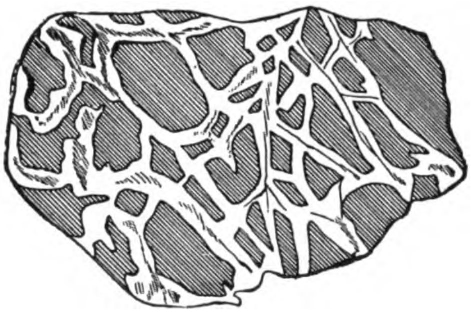


Fig. 235.—Cellular cadmia from Raibl. (Posepny.)

Limonite and unctuous, ochrous, yellow, greenish or brown clays also occur in cavities in the cadmia masses.

Interesting conditions were disclosed by breaking into the 'grotto,' a cave tapped in 1892 in the 7th Johann-Firstenlauf. This cave connects with the east fissure, and its walls are coated with stalactites of blende and cadmia, as well as with crystals of galena, cerrusite and wolfenite. The latter minerals may be of secondary nature and deposited by descending waters.

Mining at Raibl began at an unknown date in the Middle Ages. In 1762, the Treasury purchased several shares in the mines and this led to the stimulation of the industry. In 1898, the Raibl field produced 2,046.9 tons of lead ore and 320.6 tons of lead, besides 12,384.9 tons of zinc ore.

14. *The Lead Deposits of Bleiberg in Carinthia*[1].

Bleiberg, which is situated about 12 km. (7 miles) west of Villach in Carinthia, is next to Raibl the most important lead and zinc deposit of

[1] F. Mohs: 'Die Gebirgsgesteine, Lagerungsverhältnisse und Erzlagerstätten zu Bleiberg in Kärnthen,' 1810 (manuscript). C. Peters: 'Ueber die Blei- und Zinklargestätten Kärnthens,' *Oesterr. Zeitschr.*, 1863, p. 173. E. Suess: 'Geogn.-Berg-

Carinthia, its mines being many centuries old. The town lies in a deep gorge between the Dobratzsch at the south and the Erzgebirge at the north[1]. The first named mountain is well known on account of the great land slide of 1348, which fell into the Gail valley. The valley, according to Geyer, is a syncline cut through by the Bleiberg fault, which has dropped down the north flank (Erzberg) of the syncline, as compared to the south flank (Dobratzsch).

The Bleiberg deposits like those of Raibl lie in the ore-bearing limestone immediately below the Triassic Raibl slates. At Bleiberg the ore-bearing limestone is dolomitic in greatly varying proportions ($MgCO_3$ 0.1-40%), and often encloses minute quartz crystals. Because of its fissured condition this limestone, which is here a fetid bituminous rock, is permeable to water, just like the principal dolomite bed overlying the Raibl slates, while the slates are impervious.

The main mass of the Erzberg consists of the ore-bearing limestone. Overlying slates and swinestone are seen only near Rubland on the north and southward at the Bleiberg valley, the dip at the first place being north, at the latter south. These rocks represent the ends of a dissected arch, remnants of a solid anticline that once spanned the mountains but is now denuded. The entire south flank of the mountain is lowered to the southward by a great number of faults, individually of but very little throw, but aggregating a considerable amount, and breaking the mountain mass into many separate blocks.

The ore deposits of the Bleiberg, like those of Raibl, are metasomatic replacements with distinct cavity fillings, and are found with very few exceptions in the ore-bearing limestone. The cavities have the form of pipes or tubes (Schlauch-form, Posepny's term). The axial lines of the ore pipes (as pointed out by the Mohs at the beginning of the 19th century) are formed by the intersection of two planes, viz.: the bedding plane of the ore-bearing limestone and cross fissures. Some bedding planes "prove to be especially favorable or rich," and the same is also true of certain fissures. The fissures are characterized by an abundance of clay, the bedding planes by distinct evidences of water circulation. Sometimes, too, the pipes of ore occur in the immediate neighborhood of the so-called cross slates, or intercalations of slates in the ore-bearing limestone which traverse it across to the bedding. They are alleged to be Raibl slates pressed into fissures. Most likely they are fault clays.

männ. Skizze von Bleiberg,' *Oesterr. Zeitschr.*, 1869, pp. 259-262, 266, 267. F. Posepny: 'Ueber alpine Erzlagerstätten,' *Verh.* d. k. k. geol. Reichsanst, 1870. Hupfeld: 'Der Bleiberger Erzberg.' *Zeit. f. Prak. Geol.*, 1897, pp. 233-247, gives full review of literature.

[1] G. Geyer: 'Zur Tektonik des Bleiberger Thales,' *Verh.* d. k. k. geol. Reichsanst, 1901, pp. 338-359.

How far down the columnar ore shoots, or rather the line of such 'pipes' continue, has not yet been ascertained. At the present time the very deepest, lying more than 400 m. (1312 ft.) below the floor of the valley in the Kreuther field, are the richest. In every case, however, they are restricted to a zone 500 m. (1840 ft.) wide of the ore-bearing limestone in the neighborhood of the slate. Detached occurrences of ore, for that matter, are also found in the slate itself and in the fetid limestone. Even in detail the orebodies are clearly seen to follow the planes of rock parting, as shown in the section, Fig. 236.

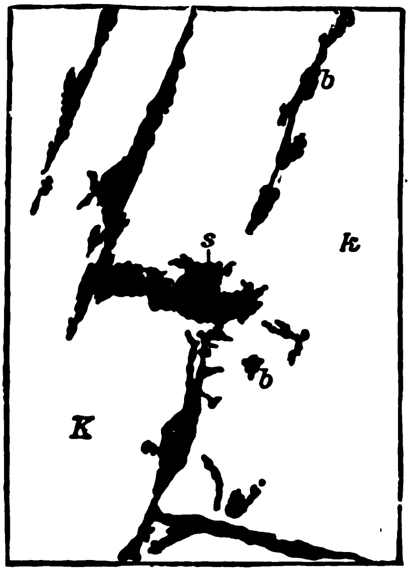


Fig. 236.—Section across the orebodies of Wetterthürverhau.

The following minerals constitute the vein filling: (a) Primary: galena, zinc-blende, marcasite, barite, fluorspar, calcspar, dolomite spar. (b) Secondary: cerussite, plumbocalcite, anglesite, yellow lead ore (wulfenite), zinc spar, hydrosilicate of zinc, zinc bloom, brown hematite, anhydrite and gypsum. Anhydrite occurs in very considerable bodies. Asphaltic substances were also observed[1].

[1] H. Höfer: 'Erdölstudien,' *Sitzungsber.* Kais. Ak. W. Vienna, Math-.Phys. Cl., Vol. CXI, part I, July, 1902, p. 27. This remarkable work, recently published, discusses the widespread distribution of bituminous material in ore deposits of all kinds, including veins, and the significance of this fact in its relation to ore genesis. The author explains the paragenesis of argentite, native silver, and anthracite in the Kongsberg veins, as due to the action of currents of CO_2, the reaction, as experimentally determined, being $2Ag_2S + CH_4 = 4Ag + 2H_2S + C$.

The great purity of the Carinthian galena, its freedom from antimony and copper, have made the Carinthian 'virgin lead' famous. The Bleiberg-Kreuther field in 1898 produced 4,681.5 tons of lead ore (including 53.3 tons yellow lead ore) and 3,640.2 tons of lead, as well as 3,088.8 tons of zinc ore.

Quite similar conditions are exhibited by the lead mines at Rubland in lower Carinthia, which stopped operations in 1897[1].

15. *The Silver- and Gold-bearing Lead Deposits of Mapimi, Durango, Mexico.*

The vast deposits of silver- and gold-bearing lead ores at Mapimi, in Mexico, according to E. Naumann[2], form a system of columnar ore shoots in the middle Cretaceous limestone. The ore shoots are associated with great fissures and lie in a downthrown area, a "zone of collapse," at the foot of the Bufa, a block of Cretaceous limestone 2,400 m. (8,872 ft.) high. The main deposit is the Ojuela, a pipe of ore 30 m. (98 ft.) in diameter and opened to a depth of 500 m. (1,640 ft.) Judging from specimens seen, the mass filling these tube-shaped masses has the following character:

In the undecomposed condition, as it appears in the so-called arsenopyrite depression of the Ojuela, the ore minerals are galena, arsenopyrite, chalcopyrite, pyrite, zinc-blende, boulangerite, red silver ore, gray copper and antimonite; the gangue is of quartz, fluorite, barite, calcite, rhodochrosite and ankerite. A compact mixture of arsenopyrite, galena, pyrite, zinc-blende and fluorite decidedly predominates. The minerals also occur crystallized in druses. The boulangerite is usually intimately coalesced with asterated quartz. As the ground-water in the mines of the Ojuela has been reached only at great depth, beyond 500 m. (1,640 ft.), probably because the fissures draw off the water, the great downward extension of the gossan is not surprising. Within this gossan formation there are found, as secondary minerals, cerussite with remnants of yet undecomposed galena, hydrated lead antimonite (in part formed direct on the boulangerite), wulfenite, cadmia (calamine and smithsonite), limonite, pyrolusite and antimony ocher. True secondary silver ores are indeed not visible, but may be present as finely divided cerargyrite, since there is considerable silver in the ore. Mention must also be made of secondary calcspar and aragonite.

[1] R. Rosenlecher: 'Die Zink- und Bleierzbergbaue bei Rubland in Unter-Kärnthen,' *Zeit. f. Prak. Geol.*, 1894, pp. 80-88.

[2] E. Naumann: 'Ueber eine Reise nach Mexico,' *Z.* d. D. G. G., 1899, Vol. L, part III, p. 106.

The Mapimi ores contain on an average 18% lead, 0.06% silver and 6 g. of gold per ton. The output in 1897-8 (to June 2d) was nearly 70,000 tons.

To explain the origin of these deposits, E. Naumann imagines that the ore chimneys were formed by the explosive pressure of steam and by the widening of the pipes by the rising of acid fumaroles. As the filling of the Ojuela contains no pyroclastic products, such violent processes seem rather improbable. However, the rising of hot springs, mineralizing the limestone and undoubtedly following the intersections of tectonic fissures, may have been an echo of volcanic processes. It is to be noted that the limestones at the Sierra de la Cruz near the Ojuela and near San Ramon have undergone contact metamorphism by plutonic masses. They carry yellow garnets, vesuvianite, light-colored mica and green translucent spinals, or they are marmorized. The formation of the ore may also be connected with these processes.

16. *Silver-Lead Mines of Santa Eulalia, Chihuahua, Mexico*[1].

The great lead deposits of this locality are about 12 m. southeast of the city of Chihuahua.

The mines are in a northeast to southeast range of arid and barren mountains which are formed of Cretaceous limestone, cut by eruptive rocks, and in part covered by rhyolite tuffs laid down on very irregular and rugged surfaces. The limestones form a dome with gentle dip (5° to 15°). The mines all occur in this limestone dome, which is now deeply scored by narrow gulches. The ore deposits form great masses of irregular shape, in the limestone, following and in part limited by stratification planes. Most of the orebodies lie on the floors of great caverns, and hence correspond to the type called by Newberry "chamber deposits." There is unquestioned evidence, however, that these caverns are formed by later circulating waters. The orebodies are sometimes connected by fissures, and are themselves more or less connected either by films of red clay or by a limestone checked and netted by minute fractures filled with iron oxide. The ores are mainly oxidized and consist of more or less impure cerussite, sometimes showing nucleal cores of galena. The replacement of the limestone is indicated by lines of chert corresponding with similar lines in unaltered limestone walls, and by the presence of silicified fossils in the ore. The ore carries variable amounts of silver, but averages about 25 ounces per ton. The mines were discovered in 1591, but did not become noteworthy producers until 1705.

[1] From observations of W. H. W. See 'Notes on Mines in Chihuahua,' *Trans*. Am. Inst. Min. Eng., Vol. XXXII, 1902, p. 396. Also, R. T. Hill, same vol., p. 174. Jas. P. Kimball, Am. Jour. Sci., 2d series, Vol. XLVIII, 1869, p. 379.

The total production on which taxes were paid for the years 1705 to 1791 was $112,000,000. The district is now one of the chief producers of Mexico.

17. *The Sierra Mojada Silver Mines, Mexico.*

The mines of this name[1] are situated on the northern foot-slopes of a steep mountain front rising 3,000 ft. above a narrow desert valley. The mountain is formed of Cretaceous limestones, mostly horizontal, which are older than and lie under volcanic breccias and tuffs forming the lower foot-slopes. The ore deposits occur either along the contact between these

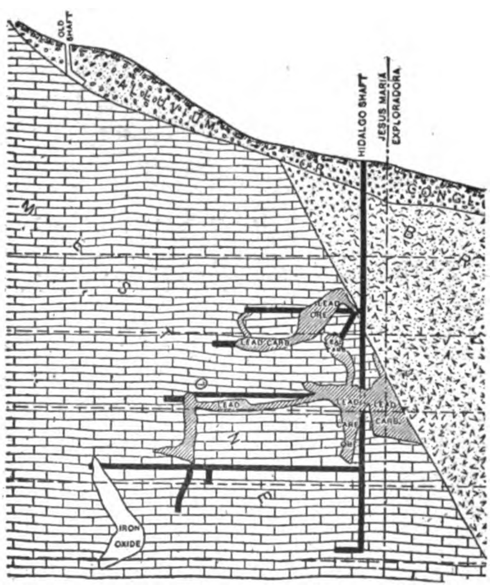


Fig. 236*a*.—Cross-section through the orebodies at Sierra Mojada, Mexico. (Malcolmson.)

Orebodies in limestone. Breccia of volcanic rock to right of fault. Capping of conglomerate.

rocks, or in the limestone. The great orebodies are 'chamber' masses in part along fissure lines transverse to the contact, but connecting with the contact orebodies. These masses occur more or less along the bedding planes, are roughly horizontal, and 2 to 40 ft. thick, often having pipe-like extensions for 100 ft. or more downward into the limestone. These carbonate orebodies carry 12 oz. silver per ton, and 15% lead. The impregnations consist of limestone, with disseminated silver chloride, and with the addition of silica when near the breccia contact. The contact

[1] James W. Malcomson: 'The Sierra Mojada, Cohuila, Mexico, and its Ore Deposits' *Trans.* Am. Inst. Min. Eng., Vol. XXXII, 1902, p. 100.

orebodies are less important, and in one case consisted of copper ore. The district produced 200,000 tons of ore annually from 1886 to 1900, but is now declining.

(e) Epigenetic Stocks of Gold Ore.

1. *Refractory Siliceous Gold Ores of the Cambrian Rocks, Black Hills, South Dakota*[1].

These deposits occur in the Bald Mountain, Portland, Crown Hill and Sheeptail Gulch districts of the Black Hills in South Dakota.

The almost horizontal Cambrian, resting, unconformably on upraised Algonkian schists, usually begins with a basal conglomerate. Above this a quartzite frequently follows, and immediately above this a calcareous

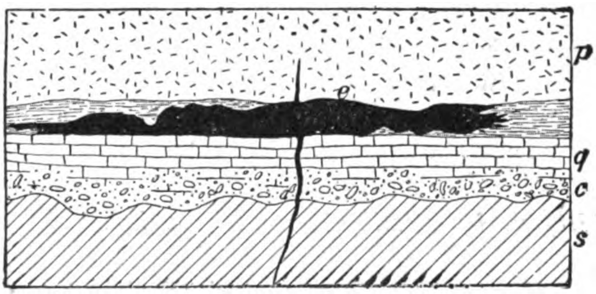


Fig. 237.—Cross-section of an orebody of the American Express Gold Mine. (Irving.) p, porphyry; q, quartzite; c, conglomerate; s, crystalline schist; e, ore; height, 5m.

sandstone or impure dolomite, usually overlain by the ordinary sandstones and slates of the formation, sometimes with porphyritic intrusive sheets.

The orebodies are found within the dolomitic strata immediately above the quartzite, in some cases also within calcareous horizons situated higher. In form they are very irregular, but are always flat extended masses, never exceeding, in a vertical direction, the thickness of the calcareous layer. Along their sides they appear dovetailed, as it were, with the normal stratified rock (see Fig. 237). Longitudinally they are always traversed by a vertical fissure (a 'vertical'), carrying the same ores, which may be followed for some distance into the underlying strata.

The ore is a hard, brittle rock composed of secondary silica and carrying, when unoxidized, pyrite, fluorite and other accessory minerals. Although

[1] F. C. Smith: *Trans.* Am. Inst. Min. Eng., Vol. XXVII, p. 415. J. D. Irving: 'A Contribution to the Geology of the Northern Black Hills,' *Annals* New York Ac. of Sc., 1899, Vol. XII, No. 9, pp. 296-311. Also, 'Economic Geology of Northern Black Hills,' Prof. paper No. 36, U. S. Geol. Survey, 1904.

the ores contain from 124-250 grams of tellurium, 10-18 grams of gold and up to 342 grams of silver per ton, yet neither free gold nor tellurides as such can be recognized in them. Some thallium has also been found in them.

These deposits manifestly represent replacements of calcareous strata. The fissures were channels along which the ore-bearing solutions rose from the depths. In composition, but not in form, these deposits are analogous to the lode-shaped gold ore deposits of Cripple Creek. Like these they are characterized by a tellurium content and by the presence of quartz with fluorspar. Like Cripple Creek the Black Hills contain phonolites, so rare elsewhere in North America. The shafts by which the ore deposits were opened passed in part through phonolitic intrusive masses, and the ore-bearing fissures along which the mineralization of the limestone took place sometimes cling to the selvage of dikes of phonolitic or porphyritic rocks. The ores average $15 per ton in the main area.

It is to be noted that, according to J. D. Irving, zones of mineralization of the same composition are also found in the Carboniferous limestone of the Black Hills (in the Ragged Top District) where, however, they usually pass vertically through the strata (*l. c.*, p. 311).

2. *The Gold Deposits in Dolomite at Pilgrim's Rest in the Transvaal, Africa.*

Pilgrim's Rest lies in the Lydenburg district in the midst of the mountainous tract between the Olifant River at the north and the Crocodile River at the south. While the neighboring lowland is mainly made up of granite, the mountain range at Pilgrim's Rest, culminating in Mount Mauch, 2,617 m. high, is composed, according to J. Kuntz[1], of a system of slightly tilted strata whose sequence from above downwards is as follows:

3. Sandstones, alternating with clay slates, with intruded sheets and dikes of diabase and diorite.

2. Dolomite, with intercalations of slate and hornstone, 150-250 m. thick.

1. Sandstone, with two non-auriferous, or at any rate non-workable, conglomerate beds and some layers of slate.

The gold deposits are found intercalated in the dolomite at very different horizons, forming rather irregular stratiform bodies, in general parallel

[1] J. Kuntz: 'Ueber die Goldvorkommen im Lydenburger District,' *Zeit. f. Prak Geol.*, 1896, pp. 433-441. P. R. Krause in the Aufsatz: 'Erzführung der Witwatersrand-Conglomerate,' *Zeit. f. Prak. Geol.*, 1898, pp. 19-21. A. Bordeaux: 'Etudes sur les champs aurifères de Lydenburg,' etc., *Ann. d. Mines* 9, XI, Paris, 1897, p. 300. J. G. Bousquet: *Jaarrapport* van den Staats-myning. over het jaar 1896, Pretoria, 1897.

to the bedding, but in detail often traversing it. They occur as follows from above downward:

Upper group.....	Theta, Chi, Psi, and Jubilee reefs. Clewer or Morgenzon reef. Beta and Frankfort reefs.
Lower group.....	Glynn reef. Spitzkop reef. Peak reefs.

The thickness of these deposits varies greatly. In Glynn reef it is from 0 to 2.13 m., in Theta reef 0 to 2 m., in Beta reef 0 to 0.6 m., rarely more. Clewer reef is divided, by a layer of wad, dolomite or hornstone, into two stringers, whose total thickness varies between 0 and 1.5 meters. Most of the deposits rest on the dolomite, projecting into it in a number of embayments, while the ore is often overlain by a bed of hornstone and in the Beta mine also by an intrusive sheet of diorite. Displacements sometimes occur, as at the Clewer mine, whose orebody is faulted by a dike of diabase porphyry. As all the workings are as yet above ground-water level, the mineral composition of these deposits is known only in the zone of oxidation. Here their main mass consists of quartz that is sometimes compact and hard, but is usually spongy and porous, and at times quite like pumice-stone and easily crumbled into dust. The hard portions are the poorest. The gold is very finely disseminated, and but rarely recognizable with the naked eye. The orebodies also contain much iron ocher, wad, lumps of copper carbonates, especially azurite, and, at certain points, according to specimens at hand, bismuth ocher.

Through the formation of cavities in the dolomite after the deposition of the ores, and the falling in of the roof of the caverns, the deposits occasionally have been changed into a mass of débris. As the lateral leaching out of the dolomite parallel to the joints of the strata has somewhat diminished the thickness of that rock, the overlying strata, with the deposits here, have acquired a steeper dip outward. The dolomite, whose stratigraphic position suggests its identity with the Malmani dolomite, is (in the Pilgrim's Rest area) also traversed by steeply dipping gold quartz lodes. These vary from the thickness of a sheet of paper to 6 in. and lie about 15 m. (50 ft.) from one another. Despite their slight thickness, they sometimes yield a large output of coarse gold. They are said to be richest where they traverse the slates, poorer in the sandstone, and very poor in the dolomite. They are in close proximity to diorite dikes. The bed-like masses of gold ore are distinctly recognizable as metasomatic replacements of the dolomite. It seems probable that the veins just mentioned represent the channels of supply from which the auriferous solutions penetrated laterally into the rock.

A few gold deposits also occur in the slates of the upper sandstone horizon—for example, in the Finsbury and Nooitgedacht reefs, but are of slight importance.

In contrast with the Johannesburg area, the mining operators of this district have to battle with many difficulties, as the region is very rugged and the work requires a good deal of timbering, which, in this poorly wooded country, is very expensive. Nevertheless, some mines are in successful operation there.

Gold Ores of Bannock, Montana.

Deposits similar to the gold deposits of Pilgrim's Rest are found in the Golden Leaf mines of Beaverhead county, in southwestern Montana, described by R. W. Barrell.[1] Cavities partly filled with gold-bearing quartz and connected by narrow quartz stringers are there found in the limestone close to its superposition on the granite. Stringers of gold quartz are also noticed in the granite. The deposits are garnetiferous rocks impregnated with free gold and tellurides of gold, in the zone of intense contact metamorphism of Cambrian limestones altered by a diorite stock which has domed the beds.

(f) Epigenetic Stocks of Antimony Ores.

The Antimony Deposits of Kostainik[2] in Servia.

Antimony deposits forming replacements of limestones have been described from Servia, in the district of Kostainik. Besides these truly metasomatic antimonial deposits, vein-shaped deposits also occur at that locality, and for convenience and brevity we will discuss both together.

The antimony deposits of the environs of Kostainik lie in the extreme western part of the district, in the mountainous wooded basins of the Styra and Bornia rivers, which flow into the river Drina that forms the international boundary line; also in the head-water area of the Grabiteba river. The mineral districts occur along a line 16 km. (9.6 miles) long, and 1.5 km. (0.9 miles) wide, running northwest-southeast.

The main mass of the rocks in that locality is formed of light-gray to ash-gray limestones, with laminated stratification and probably of

[1] R. W. Barrell: 'The Mineral Formation of the Golden Leaf Mines,' *The Engineering and Mining Journal*, 1897, LXIV, p. 64. W. H. Weed: 'Ore Deposits near Igneous Contacts,' *Trans.* Am. Inst. Min. Eng., Oct. 1902, p. 18.

[2] R. Beck and W. von Fircks. 'Die Antimonlagerstätten von Kostainik in Serbien,' *Zeit. f. Prak. Geol.*, 1900, pp. 33-36.

Triassic age, overlain conformably by gray and blackish soft clay slates, in part also by distinctly clastic graywacke slates.

These limestones and slates are broken through at many points by biotite-trachytes, and at Ravanitza and probably elsewhere also by hornblende andesites of trachytic habit. These eruptive rocks form dikes, sheets and stocks within the strata, and also perhaps effusive lava flows. The antimony deposits are intimately connected with the igneous rocks.

The ores consist exclusively of stibnite, which has been secondarily altered into valentinite and stiblite, as well as into other forms of antimony ocher, and is accompanied by quartz and calcspar. In addition, there are very subordinate amounts of a secondary development of small, imperfectly developed crystal groups of native sulphur and sharply developed crystals of senarmontite, up to a millet grain in size.

The ores appear in three different forms:

1. *Tufts and stringers of stibnite, quartz and calcite in decomposed trachyte.*—Such ores are found in the mines of Kik and Stolitza.

2. *Antimony veins in the slates.*—In this type, of which the only example known is at Rovinè, we are dealing with a compound vein dipping at 30°. Between the two parallel bounding fissures, which intersect the stratification and schistosity of the country rock, lies a zone sometimes over 1 m. (3.28 ft.) thick, of very numerous stringers, mostly transverse, like the rungs of a ladder. The foot-wall fissure is always the richest. The hanging wall is mostly barren. The transverse stringers are cut off at the two wall fissures and are rich in stibnite, with quartz and calcspar. Outside of the zone enclosed by the leading fissures only barren calcspar stringers occur.

3. *Interbedded ore masses.*—At most of the numerous small mines and prospects stratiform deposits are worked, which are underlain by limestone and overlain by slates. A trachyte intrusion is always found near by, and narrow apophyses (*i. e.,* branches) of that rock often form the walls of these deposits or cut through the ore masses, sometimes in a direction parallel, sometimes forming an acute angle with them (Fig. 238). The deposits consist of a dark, very finely crystalline groundmass of quartz, intimately intergrown with tufts of stibnite. The dark color of the quartz is due to microscopic particles of bitumen or coal, which are especially abundant between the limiting planes of the minute polyhedric quartz grains, but also occur as inclusions in their interior. The stibnite has mostly been superficially altered into antimony ocher, stiblite or valentinite, but in many cases it has been leached out again entirely, so that the gray quartz merely contains the hollow moulds of the sheaves of antimony glance. Sometimes the quartzose ore has been crushed and

re-cemented by quartz or calcspar. In such breccia-like portions, quite irregular druses occur, whose walls are studded with quartz crystals and also show here and there minute crystalline aggregates of native sulphur and crystals of senarmontite. Sometimes, as at the Zavorie II mine, the quartzose orebodies are traversed obliquely by calcspar stringers.

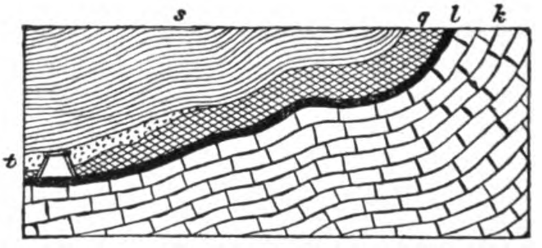


Fig. 238.—Bed-like deposit of antimony ore near Kostainik.
q, quartz layer with antimony ore; l, clay; k, limestone; s, clay slate; t, trachyte.

These ore masses are at some points intercalated between the slate and the limestone, and thus resemble beds, especially at points where, owing to folding, the parting plane between these rocks shows a wavey course in the cross-section.

In other cases, however, the ore-bearing quartz mass is seen to extend into the underlying limestones with very irregular borders, often cutting through the bedding, suggesting that considerable portions of calcium

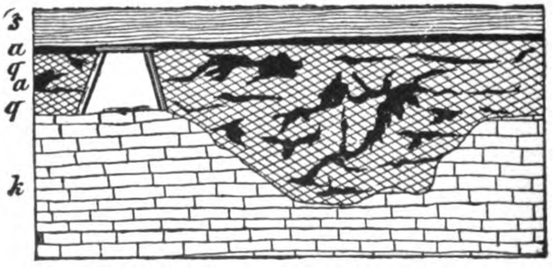


Fig. 239.—Cross-section of a bedded antimony deposit in limestone at the Zavorie III Mine.
a, antimony ore; the remainder as in Fig. 238.

carbonate have been leached out and replaced by the quartzose ore. This is exhibited especially in Fig. 239, representing a cross-section through the very rich ore mass of Zavorie III mine, which is 2 to 6 m. (6.5 to 16.4 ft.) thick. The cavity found in the underlying limestone was followed to a distance of several meters as an irregular groove. At the borders of the orebodies, both above, along the boundary of the slate or trachyte, and below, thin layers of clay are not infrequently found. Clay fissures also occur which cut obliquely across the orebodies, as for example at another place in the Zavorie III.

All the phenomena just described seem to indicate that the antimony ores of Kostainik were deposited from solutions which penetrated into the solid and already folded sedimentary rocks of this region. Whether or not these solutions derived their antimony content from a deep-seated mass of trachyte, the uprising waters being an aftermath of the processes of eruption, cannot at present be determined with certainty, though it certainly appears a very plausible theory. The solutions left their deposits not only in the fissures and clefts which formed their main channel, but penetrated also laterally into the joints between the strata of the limestone, this result occurring wherever a relatively impervious rock, the slate, checked their further rise. At the boundary of the rock they stagnated, dissolved the underlying calcium carbonate and exchanged it for the mineral burden which they had brought up with them.

Antimony Deposits in Italy.

A series of stock-shaped occurrences of antimony ore found at the boundary between the Rhaetic limestone and the Permian slate occur in Tuscany (as at Rosia near Siena, at Orbetello in the province of Grosseto and elsewhere). At Rosia the stibnite is accompanied partly by calcite, partly by quartz. The country rock is silicified. Fine groups of stibnite crystals, superficially altered to antimony ocher, are known from that locality, which are studded with crystals of native sulphur and valentinite.

Mention should also be made of the antimony stocks in the Su Suergiu mine, near Villasalto in Sardinia, which are enclosed in Devonian Carbonaceous slates near the boundary of the Silurian.

Antimony Deposits of the United States.

Antimony-bearing quartz veins are common in California and Nevada, and were worked ten or fifteen years ago. A remarkable bedded deposit occurs on Iron Creek, Coyote Co., southern Utah, the ore being an impregnation of a sandstone bed just above limestone. Stibnite occurs in tufts and radial masses, in layers ½ inch to 30 inches thick, there being no other mineral present. The deposit is regarded as an impregnation of porous sandstone layers by mineralizing hot waters, analogous to those now depositing stibnite in alluvial gravels at Steamboat Springs, Nevada.

C. CONTACT-METAMORPHIC ORE DEPOSITS.

By this term we understand the epigenetic bedded deposits and ore stocks formed within stratified rocks under the influence of contact metamorphism near or along the boundary between plutonic eruptive masses and stratified rocks. The most important criterion for the recognition and distinction of the contact-metamorphic ore deposits as compared with the other epigenetic bedded deposits and ore stocks, is the mineralogic composition. The ore is always characterized by the presence of certain minerals which we know elsewhere to be typical of igneous contact zones. Where the ores, as is usually the case, have metasomatically replaced limestones, dolomites or other rocks consisting only partly of calcium carbonate, we find, as contact minerals, garnet, epidote, light-colored pyroxenes, wollastonite, vesuvianite and other lime silicates. Contact-metamorphic ore concentrations in shales may be accompanied by andalusite, chiastolite, cordierite, scapolite, etc. The diagnosis becomes difficult when the normal country rock belongs to the crystalline schists. A sharp separation of some supposedly epigenetic ore deposits from the contact-metamorphic deposits is not yet possible. In view of the great similarity in the appearance of certain varieties of regional metamorphism with that of contact metamorphism, this can not be deemed surprising. We have already in the description of the deposits of Schwarzenberg and of Pitkäranta pointed out this relation and the kinship between the two categories, which may perhaps on further investigation prove to be even closer.

There is a very close genetic relationship between the contact-metamorphic ore deposits and magmatic ore segregations. In fact, in both types the metal content is derived from the magma.

Hence W. H. Weed, in his recent very suggestive scheme for a scientific classification of ore deposits[1], has very properly assigned to the contact-metamorphic deposits a place immediately after the magmatic segregations.

The most important ore of contact-metamorphic deposits is magnetic iron ore. Sulphide copper ores are next in importance, while a great number of other ore minerals are of lesser importance.

In many instances vein-shaped deposits are connected with contact-metamorphic ore beds and ore stocks. In fact, many of the deposits of contact-metamorphic mining districts are of diverse form, but have been bunched together in the descriptions given herein.

[1] 'The Genetic Classification of Ore Bodies,' Geol. Soc., Washn., D. C., Jan. 14, 1903. *The Engineering and Mining Journal*, Feb. 14, 1903, 'Ore Deposits, a Proposal and a Discussion,' 1903.

1. *The Ore Deposits in the Contact Area of the Granite of Berggiesshübel, in Saxony*[1].

The ore deposits of Berggiesshübel, in the so-called Elbthalgebirge of southeastern Saxony, represent a typical example of contact-metamorphic ore deposits that have been investigated with particular care, and will for that reason be described first, and with some detail, although the deposits have long lost their economic importance.

At Berggiesshübel several granite stocks occur in gently dipping slates. One of these, which, by its size and the extent of its contact phenomena, occupies the first rank, is the granite stock of Markersbach. Close to its western edge lies the mining field of the old mining town of Berggiesshübel. At this place the outcrops of the various beds of the Phyllite and lower Silurian formations are well exposed and distinctly seen abutting against the granite boundary; and from these exposures and various minor workings it is known that the surface of the eruptive stock dips at a low

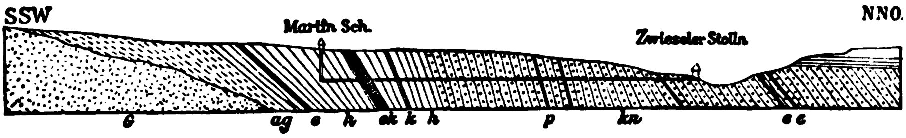


Fig. 240.—Section across the contact zone of Berggiesshübel.
G, Markersbach granite; ag, andalusite-mica rock; h, hornblende and salite schists; k, knotted slate; e, ore-bed; k, marble; p, quartz porphyry; t, Lower Turonian and Cenomanian.

angle beneath the slates. The sedimentary rocks which adjoin and in part overlie the granite have been subjected to strong contact metamorphism.

In the Silurian formation, the clay slates were changed into hornstones (Hornfels), horn schists and nodular schists, the diabase tuffs into various hornblende schists, especially actinolite schist, also banded salite-hornblende schists. The limestone beds, intercalated in the clay slates and especially in the tuffs, were, however, turned into deposits of marble or in part into salite-garnet rock beds, or finally into magnetic iron ore beds (see Fig. 240).

These limestone beds may be followed in a northwest-southeast direction, along their strike, for long distances, being exposed in many openings, deep limestone quarries and natural exposures from Maxen across the villages of Biensdorf and Gersdorf, to the point where they enter into the contact

[1] R. Beck: 'Erläuterungen zu Sect. Berggiesshübel der geol. Spezialkarte von Sachsen,' Leipzig, 1889, pp. 25-60. H. Müller: 'Ueber die Erzlagerstätten der Umgegend von Berggiesshübel,' part of geol. map of Saxony, Leipzig, 1890, with map of veins and cross-section. Gives review of literature.

area of the granite. Over this entire distance, however, these limestones are devoid of ore, with the exception of a few insignificant deposits of red and brown hematite ore, which occur for example at Nenntmannsdorf, at the slate-limestone parting.

Within the vicinity and influence of the igneous contact, however, the calcium carbonate has been partly or entirely driven out of these beds, and replaced by the material from invading siliceous and mineralizing solutions, forming salite and garnet, as well as magnetite and various sulphide ores. The distribution of the marble, calcium silicates and ores within the beds is very remarkable and varied, and clearly shows the character of this kind of replacement.

First it is to be noted that the marble still shows distinctly the stratification of the originally dense Silurian limestone from which it was derived. Furthermore, the alternation between thin limestone strata and tufaceous beds found in the Silurian of that locality is repeated in the contact area between marble and hornblende schist, except that the limestone, whenever it formed thin streaks and layers, is for the most part completely changed into a light greenish pyroxene rock.

In the thicker limestone strata of the contact zone there is frequently a sequence of several beds of marble, with intervening beds of salite-garnet rock, alternating with garnet rock and magnetic iron ore. More commonly, however, quite irregular nests and lumps of magnetic iron ore are found in the midst of the marble, and cutting across its stratification. They often penetrate into the marble with jagged or stringer-like projections. Occasionally, as for example in the levels driven in limestone from the Hermann shaft, irregular vein-shaped masses of magnetic iron ore were observed even in the midst of the limestone. On the whole, the ore clings particularly to the lower boundary of the marble bed, frequently thickening and entirely displacing it for long distances, occasionally reaching a thickness of 5 m. (Fig. 241). Finally, the orebodies are traversed at times by branching stringers of garnet rock, forming a network. This shows that the ore mass was broken, but the supply of the garnet-making materials seems to have continued after this mechanical disturbance. That disruption took place during the recrystallization and alteration of the dense limestone into marble is furthermore indicated by the frequent stringers of coarsely foliated white calcspar which traverse the blackish marble as white bands. They seem to have been formed as primary veinlets during the metamorphic process, since they occasionally carry garnet.

Besides magnetic iron ore, the deposits of that region also carry copper ores, such as copper pyrite, bornite, copper glance, and rarely gray copper ore. These yield a number of secondary copper ores, malachite, etc. Less frequent admixtures are pyrite, arsenopyrite, galena and zinc-blende.

While the immigration of all these ores into the limestone strata of the locality is beyond question, the origin of the metalliferous solutions is as yet doubtful. Two suppositions are possible. Either the metallic compounds in question were originally finely distributed in the country rock, especially in the diabase tuffs, and were carried into and concentrated in the limestone by contact metamorphism, after expulsion of its carbon dioxide, through a redeposition by the mineralizing agents proceeding from the granite; or they were brought up directly by the granite from a great depth and infiltrated into the country rock in solution in the superheated water of eruption. As all the hornblende schists and hornstones of

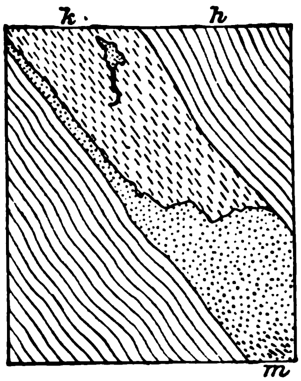


Fig. 241.—Section of the Mutter Gottes bed of Berggiesshübel.
h, hornblende schist; n, actinolite; k, crystalline limestone in magnetite.

the contact are also rich in iron, much more so than elsewhere away from the contact, the theory of the introduction of the ore by the granite has the greater probability.

The probability is increased by the fact that true veins are also known in this part of the contact zone, which carry copper ores and which in part pass through the ore-beds. They seem to represent the main channels of supply of the metallic solutions from the granite.

Finally, besides these copper veins, tin-ore-bearing stringers are also known in the beds of metamorphic limestone of that locality. They consist of orthoclase, fluorspar, quartz and lithia mica in zonal distribution. In their vicinity A. W. Stelzner also discovered tin-stone, accompanied by copper pyrite and pyrite as an impregnation in certain layers of the strata, consisting essentially of chlorite.

Thus the Markersbach granite mass is surrounded by a contact zone or halo of ore consisting of very diverse metallic compounds.

2. *The Magnetic Iron Ore Deposits of Schmiedeberg in the Riesengebirge, Germany.*

According to the recent investigations of G. Berg[1], the magnetic iron ore beds of Schmiedeberg also belong to the contact-metamorphic deposits.

Schmiedeberg lies on the north slope of the range, close below the pass leading from the Hirschberg basin over toward Landshut, within an extensive area of younger porphyritic granite. The ore deposits above the town, in the mines of the concession, lie, on the contrary, in a zone of steeply dipping, crystalline schists, with north-northeast strike, lying south of the granite. These rocks, to the northwest, consist mainly of gneiss-like Archean granites, with intervening layers of fine-scaly gneisses and mica schists. To the southeast the rocks consist of amphibole schists and chloritic mica schists with limestone beds. The ore beds form intercalations in a group of limestones, amphibolites, biotite and muscovite schists, adjoining the gneisses and mica schists. The limestones of this ore-bearing stratified series are always granular-crystalline, and, by their transition into lime-silicate rocks with garnet, salite-like pyroxene, epidote, amphibole, chlorite, vesuvianite, scapolite, fluorite, spinel and titanite, betray their contact-metamorphic alteration by the neighboring porphyritic granite. To a similar influence are probably due the horizontal veins, called "Riegel" (bars), of a pegmatite-like rock, traversing the ore deposits, and finally the concentration of the ore may itself be a contact phenomenon.

Ten ore beds are distinguished in the mines, but they do not all appear in any one cross-section. The thickness of the workable portions is usually 2 m. to 3 m. (6.5 ft. to 9.8 ft.), rarely more, though sometimes rising to 7 m. (23 ft.) Most of the ore beds are overlain by limestone and underlain by biotite schist or amphibole schist. In the granular magnetite of the beds, chlorite, garnet, pyroxene, epidote and calcite are interspersed, sometimes also pyrite, magnetic pyrite and copper pyrite. The sulphides, together with calcite, form stringers in the lime-silicate rocks, being evidently the last formed of the minerals.

Schmiedeberg is said to have been founded as a mining town as early as 1148. In recent years the mining industry, formerly subject to many vicissitudes, has entered on a renewed period of activity. In the year

[1] G. Berg: 'Die Magneteisenerzlager von Schmiedeberg im Riesengebirge,' *Jahrb. d. kgl. preuss. Geol., Landesanst.*, 1903.

1899, the Bergfreiheit mine yielded 24,000 tons of iron ore containing 50% to 60% of iron.

3. *The Iron Ore Deposits of the Schwarzen and Gelben Krux, Germany.*

The magnetic iron ores of the Schwarzen and Gelben Krux, near Suhl, in Thuringia, may, as a result of the petrographic investigations by K. Schlegel[1], be positively classed as contact-metamorphic formations.

A tourmaline-bearing granite, carrying allanite and fluorspar near the ore deposit, has broken through Cambrian clay slates. Near the Krux mines the slates are transformed about the contact into hornstones, which at some points are characterized by cordierite, tourmaline and garnet, at others by andalusite, and sillimanite. Tourmaline-bearing quartzites also occur. The magnetic iron ores, which probably were worked as early as the beginning of the 10th century, belong to this contact zone. Their granular-crystalline mass always has fluorspar mingled with it, often also wolframite, molybdenite, hematite, allanite, barite and pyrite. Sometimes a good deal of quartz is added. From one of the abandoned shafts, greenish-yellow garnet rocks were also obtained, with intermingled calcite, barite, feldspar and magnetite. B. von Cotta mentions a tin content in the ores.

We are of the opinion that the ore deposits were derived from a contact-metamorphic mineralization of calcareous intercalations.

4. *The Contact Ore-Deposits of the Banat, Hungary.*

South of Temes river, which issues from Transylvania, a range of mountains, with a mean altitude of 800 m., extends from north-northeast to south-southwest toward the Danube and beyond it into Servia. This range consists first of strongly folded mica schist, gneiss, granulite and quartzite; next of mineral-bearing Carboniferous strata, red Permian sandstone and limestones of the Jurassic and Cretaceous.

The sediments just referred to represent the filling of great synclines of the Archean schists, and consequently extend in long troughs parallel to the main strike of the mountains.

A north-south fault fissure, recognizable for a great distance, extending far into Servia, traverses this mountain range thus briefly sketched, cuts off the Mesozoic strata sharply toward the west, and has been the path of invasion of younger eruptive rocks. The latter can be traced, not in

[1] K. Schlegel: 'Die Magneteisenerzlager vom Schwarzen Krux bei Schmiedefeld im Thüringer Wald,' *Z. d. D. G. G.*, 1902, Vol. LIV, pp. 24-55; gives other literature of Krug von Nidda, H. Credner and B. v. Cotta.

perfect continuity, it is true, for a distance of 78 km. (46 miles) (see sketch-map, Fig. 242). These eruptive masses are in close genetic connection with all the ore deposits occurring in the Banat.

The miner in the Banat uses the name "syenite" to designate the rocks of varying development, of granitic, porphyritic, probably also felsitic structure. Von Cotta called them "banatites," Vom Rath and Niedzwiezki, after accurate petrographic investigations, called the most widely distributed type "quartz diorite," while Szabo calls it quartz-andesine-trachyte. Von Halavats having shown that the rock in question, southeast of Raffina, overlies a block of the Leitha limestone, it may without question be ranked among the younger eruptive rocks. According to Szabo's investigations, the banatites consist of triclinic feldspar, monoclinic amphibole, biotite and quartz, with which orthoclase is pretty constantly though subordinately intermingled. Hence the rock may be called andesite, or more accurately a quartz-andesite or dacite. It is to be noted, however, that the typical development of the rock possesses a crystalline structure, and a glassy groundmass is entirely wanting. For this reason, and from geological occurrences of the rock, it is inferred that we are dealing with an andesitic magma, rich in silicic acid, congealed under the sedimentary strata, and having the structure of a plutonic rock, while its branches may show a porphyritic or even felsitic character.

Where this dacitic rock came in contact with the Mesozoic limestones, it caused important contact phenomena, as would be expected from its plutonic nature. On the one hand, the dense limestone has been transformed into marble, and on the other, typical contact minerals, such as garnet, vesuvianite, wollastonite, tremolite, bluish calcite and radial pyroxene, have been formed. A lime-silicate-hornstone is also often found, which may have originated from a marly limestone stratum.

These various formations are distinguished under the names "Lagerarten" (bed-matrices) or "Gangarten" (gangues), or "Scheidung" (partition), and at some points attain a thickness of 300 m. (south of Arpad mine, near Dognacska). For the most part they naturally occur at the contact of dacite and limestone, but they are also found between Archean schists and dacite and Archean schists and limestone. At any rate, the eruptive rock is always to be found near by; in fact, according to Vom Rath's observations, the entire region seems to be permeated by eruptive dikes and intrusions.

According to the microscopic investigation of Sjögren the *"garnet rock,"* the most common contact product, which to the eye appears composed exclusively of brown or yellowish-green, often finely crystallized garnet individuals, contains, besides the main ingredient just named, min-

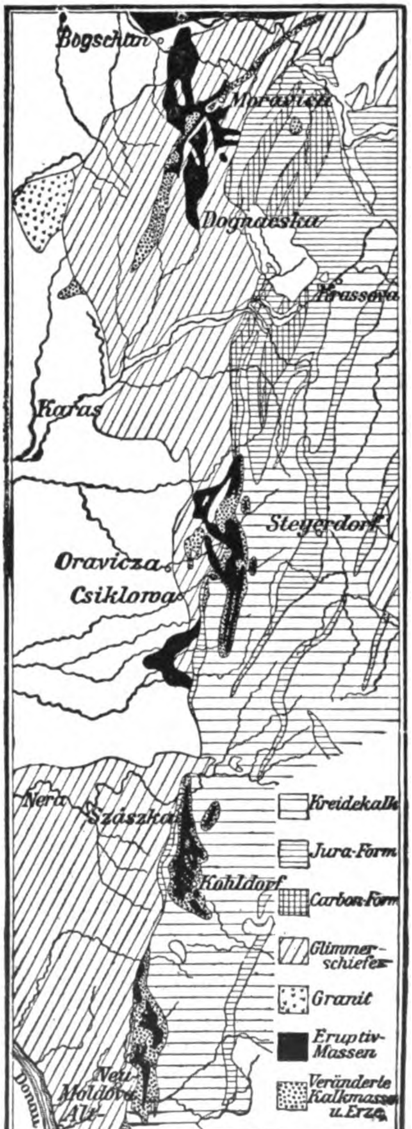


Fig. 242.—Geological sketch-map of the Banat mineral district. (E. Suess.)

erals of the amphibole group, quartz, pistacite and calcite, all of which form a part of the rock. A majority of all the ore masses are associated with these contact beds, though orebodies in the pure limestone, or in the dacite directly at the contact, are not uncommon. All the occurrences are characterized by irregularity both in extent and in ore content. Often the entire contact zone appears finely impregnated and veined with ore. In other cases merely irregular nests occur, while elsewhere massive orebodies, the ore stocks, predominate. Lode-like masses, too, have been observed. The nature of the ores is not less varied than the mode of occurrence. In the western sedimentary zone it was mainly the copper ores that induced mining. They were as follows: Copper glance, bornite, gray copper, chalcopyrite and pyrite, also galena, zinc-blende, magnetite, and at a few isolated localities native gold, arsenopyrite, stibnite, molybdenite and cobalt pyrite.

All these mineral fields, which extended around the towns of New Moldava, Szaska, Csiklova and Oravicza, have a very ancient history. In Roman times they were flourishing, while at the present day they are nearly all idle. The only one that is still of importance is the iron ore deposit of Dognacska and Moravicza, which is connected with the smaller limestone zone situated east of the main mountain range. This iron-mining industry, which produces magnetite, together with red and brown hematite, has been a prominent producer since the beginning of the 18th century. In 1890 the production was about 1,000,000 tons, most of which is consumed by the Reschitza furnaces. In former times, Dognacska was also known as a copper deposit, and even to-day copper, lead and zinc ores occasionally accompany the iron ores, without, however, being of any importance.

It is interesting to note that these ores, particularly those of the copper mines, usually held a small amount of gold; also that the dacite occasionally (for example, at Moravicza) is traversed by true gold quartz veins, which carry pyrite in the quartzose gangue, and possess the unusual peculiarity of carrying fine sprinklings of magnetite (see Marka, page 339).

A brief description of the various mine fields from the south end northward is added.

New Moldova.—This is probably a very old mining field, for here, not far from the Roman station of Versecia, were the "hundred shafts" (*centum putea*) mentioned by Tacitus. Irregular, branching intrusions of dacite occur along the boundary between Cretaceous limestone and mica schist and give rise to contact formations. Besides garnet rocks, this region seems to be characterized by the presence of silicates in the altered calcareous strata. Before 1860 copper ore alone was mined. The ores then found were mainly copper glance, bornite, chalcopyrite and the salts derived from the alteration of these sulphides. Native copper, too, is said to have occurred quite frequently. Later on the mining was mainly confined to pyrite, which accompanies the ore in great masses. Two vast pyrite masses, the Johann-Evangelista and the Fridolin pyrite stocks, both situated at the contact of garnet rock and dacite, are of especial importance. The pyrite was mined solely for the manufacture of sulphuric acid.

It is interesting to note that to the south of the Benedikter Gebirge, where lead ores were formerly mined, they were associated with a hornstone containing octahedrons of fluorspar in numerous quartz druses (see von Cotta, p. 48).

Szaska lies close to the west boundary of the western sedimentary ranges. The dacite outcrop is 9 to 10 km. (5.4 to 6 miles) long and averages 100 to 400 m. (328 to 1,312 ft.) wide, and sends out innumerable branches and smaller massives (see Vom Rath, p. 48). The contact formations are less extensive, but in other respects correspond closely to those of New Moldova. In the northern part of this district copper ores, mostly rich, occurred, and tremolite seems to have been a predominant gangue (see Castel, p. 441). The most important mine is "Ritter St. Georg," in which the ores, mainly copper pyrite and pyrite, occur in irregularly shaped and irregularly distributed nests, which, as a whole, represent a zone parallel to the contact (see von Cotta, Fig. 12, p. 53). To the south of this area, at the villages called Maria Schnee and Kohldorf, the iron ores predominate by far over the copper ores, occurring partly as oxides, partly as sulphides.

Oravicza-Csiklova lies about 18 km. (11 miles) north of Szaska. At this place the contact rocks are the main carriers of the ore, though compact orebodies are found but rarely, the ores being distributed in fine veinlets through a well-defined zone of the contact rock, which thus constitutes the so-called stockwork. Other more compact orebodies, the so-called Butzenwerke (Butzen, cone or lump), were merely of subordinate importance. According to Marka (see p. 313), contacts of different rocks seem to be accompanied by correspondingly different kinds of ores. Thus at the contact of dacite and limestone the ores were mainly pyrite and copper pyrite; at the contact of syenite and hornstones they were copper pyrite, arsenopyrite and tetrahedrite, while between dacite and mica schist ore was but rarely observed. The richest ore masses occur where the contact is with garnet rock or limestone, copper pyrite, gray copper, arsenopyrite, zinc-blende, galena and pyrite being present. The most important mines were the Baron and Speis shafts at Csiklova (see von Cotta, Fig. 13). Small ore-bearing fissures found in the dacite and carrying copper pyrite and pyrite must be regarded as true veins. Where they cross one another, orebodies occur that are rich enough to work.

A very remarkable gold deposit is situated somewhat to the north of Oravicza, but, like all the mines just described, it is at present unworked. A funnel-shaped mass, triangular in outline and about 180 m. in diameter at the bottom of the drift, is bounded by bluish calcareous marl, garnet rock and mica schist. The entire space is filled with a clayey, occasionally sandy mass, in which are imbedded fragments of limestone, garnet rock and mica schist, as well as a granite-like rock (probably a modification of dacite, since Marka mentions intrusions of "syenite"). Both in the clay filling and in minute fissures in the fragments free gold occurs, in the form of delicate scales or granules, more rarely as wire gold. The accompanying ore minerals are pyrite, chalcopyrite, tetrahedrite, bismuthinite and smaltite. The two last-named minerals are regarded as favorable for gold (see Marka, p. 455). There is, according to the descriptions, a friction breccia which appears to be the product of a movement occurring after the metamorphosis of the limestone. Subsequent intrusions of a dacitic (?) magma have penetrated into this breccia. That the dacite may be a carrier of gold is proved by the gold quartz lodes in the dacite near Moravicza, already noted.

Moravicza-Dognacsky.—As already mentioned, the mines near these towns are the only ones now being worked. The magnetite deposit is associated with a zone of Cretaceous limestone east of the main area of the Banat Range (after Halavats). The limestone forms a closely and narrowly compressed syncline in the Archean schists (mica schist, phyllite, granulite and quartzite), extending from Ezeres on the north to Kalina on the south, a distance of 17 km. There are but two breaks in the continuity of the rocks, whose outcrop varies from 30 to 100 m. in width. This strip of limestone is intersected at an acute angle by a large eruptive mass, striking northwest, so that there is a contact between the two rocks for a great distance. For this reason part of the limestone syncline is surrounded by a mantle of contact formations, in such way that these either occur between limestone and dacite or else between limestone and mica schist (see cross-section, Fig. 243). The deepest part of this limestone trough has been reached at different depths in the various mines, so that there can be no doubt of the nature of the structure (see Marka, table of profiles). The contact zone has a thickness of 20 to 300 m. (65 to 984 ft.) and consists mainly of garnet rock, but tremolite and a black, radial pyroxene also occur, as well as the secondary minerals derived from various contact products, such as serpentine, allophane, schweizerite, chlorite, etc. In these congenial beds the magnetite is either distributed irregularly or occurs as massive, stock-like orebodies, up to 150,000 tons in weight. Under the microscope, garnet and magnetite seem to be of simultaneous origin, as is indicated also by a platy intergrowth of garnet and magnetite (the so-called band ore).

Copper ores were formerly obtained from the Dognacska region, though at the present day the iron ores, magnetite, hematite and limonite are alone of economic importance. The following minerals occur: Galena and its alteration products, bornite, tetrahedrite, blende, pyrolusite, pyrite, gold—in brief, all the ores which we found to be of importance in the other deposit. A further fact of interest in the present connection is the presence of veins and stringers of magnetite in granular limestone, observed by Vom Rath in the Arpad mine (see Vom Rath, p. 47), an occurrence which appears to be as remarkable as the above mentioned gold quartz lodes in dacite at Moravicza, which contain magnetite

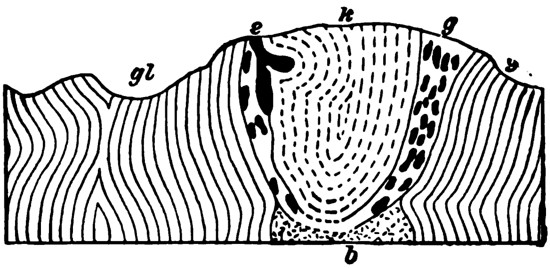


Fig. 243.—Cross-section of the limestone syncline of Moravicza at the Paulus mine; from local surveys.

gl, mica schist; k, crystalline limestone; b, banatite; e, magnetite; g, garnet rock.

finely interspersed. (Compare the magnetite stringers in limestone at Pitkäranta, p. 440.)

A close analogy exists between certain deposits in the Banat and those of Rodna, in the head-water area of the Szamos, in Transylvania, which have been described in detail by F. Posepny and others.[1]

[1] The most important publications (since 1863) on the ore deposits of the Banat: B. v. Cotta: 'Erzlagerstätten im Banat und Serbien,' 1864. G. Marka: 'Einige Notizen über das Banater Gebirge,' *Jahrb.* d. k. k. geol. Reichsanst., 1869, p. 312 *et seq.* Joh. Kudernatsch: 'Geologie des Banater Gebirgszuges,' *Sitzungsber.* d. k. Ak. d. Wiss. in Vienna, 1857, Vol. XXII, pp. 39-148. Niedzwiedzki: 'Zur Kenntniss des Banater Eruptivgesteins,' Tschermak's *Mitt.* 1873, p. 255. G. vom Rath: 'Vorträge und Mittheilungen,' *Sitzungsber.* d. niederrhein. Gesellschaft f. Natur- und Heilkunde, Bonn, 1879, p. 38 *et seq.* H. Sjögren: 'Beiträge zur Kenntniss der Erzlagerstätten von Dognacska und Moravicza,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1866. v. Halavàts: *Jahrsber* d. k. ungar. geol. Anstalt, 1887, 1888, 1889, *et seq.* *Oesterr. Zeitschr.* f. B. u. H. Das Eisenerzgebiet von Dognacska und Moravicza im Banat, 1891, p. 91 *et seq.* *Geologische Spezialkarte* d. k. ungar. geol. Landesanstalt. 1: 75,000.

Literature on Rodna: F. Posepny: 'Ueber die Natur der Erzlagerstätte von Rodna,' *Verh.* d. k. k. geol. Reichsanst, 1870, p. 19. G. vom Rath: Z. d. D. G. G., 1878, Vol. XXX, p. 556.

5. *The Contact Deposits of the Christiania Region.*

The fact that the ore deposits in the vicinity of Drammen, near Christiania (consisting mainly of magnetite and hematite but showing considerable variety of mineralogic development), occur in the contact zone between Paleozoic rocks and granites, and in part occur at the very contact itself, was recognized many years ago by Keilhau,[1] and this has been confirmed by A. Daubrée and Th. Kjerulf.

According to J. H. L. Vogt, this group of deposits comprises at least a hundred and probably several hundred deposits, mostly rather small, "which must beyond question be regarded as contact products of the granites with the various pre-granitic rock members (basal complex, Silurian and porphyry sheets)." In support of this view, that author gives the following statistics. Among 104 accurately examined pits and prospects:

(I) 17 deposits are found within Silurian rocks enclosed by granite.

(II) 22 are found exactly at the boundary between granite and Silurian, or within 10 m. from the boundary, the ore being always enclosed in the Silurian strata.

(III) 48 are found in the Silurian contact zone, mostly 0.1 to 0.5 km., in some cases 1 to 1.5 km. from the granite boundary.

(IV) At most ten lode-like bodies occur in the gneiss.

(V) Many such veins occur in the augite-porphyrite near the granite boundary.

Most of these deposits are intercalated approximately parallel to the stratification of the slates and limestones. Many are cut by tongues of the granite intrusions and dikes of quartz porphyry (granophyre) and of various granites, proving that they were formed before the last phase of eruptive activity had closed. The country rock shows intense normal contact metamorphism, with the formation of new garnet, vesuvianite, scapolite, biotite, pyroxene, hornblende, epidote, chiastolite, etc. The ores, which have not only replaced limestone, but even more frequently slate, consist of the oxides of iron with subordinate amounts of copper pyrite, argentiferous galena, blende, iron pyrite, arsenopyrite, smaltite, bismuthinite and molybdenite. Calcspar, fluorspar, apatite, garnet, epidote, rarely also axinite and helvine, accompany the ores.

[1] B. M. Keilhau: 'Gaea Norvegica,' Christiania, 1838. Vol. I, pp. 61-69, 73-83, 107, 109, 125. A. Daubrée: 'Skandinaviens Erzlagerstätten,' Uebers. durch v. Leonhard, 1846, pp. 26-56. Th. Kjerulf: 'Ueber die Geologie des südlichen Norwegens,' Christiania, 1857. W. C. Brögger: 'Die silurischen Etagen 2 und 3 im Kristianiagebiet,' etc., Christiania, 1882. Also 'Die Eruptivgestein des Kristiana-Gebietes,' I-III, Vidensk. Selsk. Skr., Christiania, 1894, 1895, 1897, and 1898. J. H. L. Vogt: 'Dannelse of Jernmalm,' *Geol. Fören. Förh.*, 1891, Vol. XIII, p. 735 and 1892, Vol. XIV, p. 211. Résumé in German, pp. 243-245.

Thus even the iron deposits show examples characteristic of the tin deposits. It is worthy of note that the various facies (distinguished by W. C. Brögger) of the plutonic rocks of the region are not uniformly favorable for the development of ore deposits at their contact. The nepheline and augite syenites are bordered by very scanty deposits of sulphide ore. The three granitic members of the eruptive series, nordmarkite, soda granite and granitite, on the contrary, are surrounded by a border of ore deposits, while the diabase dikes which represent the closing act of volcanic activity are associated with merely local deposits of galena and zinc-blende with fluorspar.

Mining operations at all these contact deposits are at present either quite insignificant or entirely stopped.

6. *The Ore Deposits of Traversella and Brosso, Italy.*

Between Traversella and Brosso, in Piedmont, a diorite stock, probably of Tertiary age[1], is intruded in mica schists containing intercalations of crystalline dolomite. At Traversella[2] the limestone near the contact is in part altered into a fine-grained crystalline garnet-pyroxene rock with epidote, amphibole and traversellite; another part is replaced by ore. In the Montajeu and Gias de Gallo mines magnetite alone occurs, while in the Riondello mine near Traversella the ore is a mixture of magnetite with pyrite, the latter sometimes forming large masses of nearly pure chalcopyrite. The subordinate minerals include pyrrhotite, marcasite, arsenopyrite, galena, zinc-blende, stibnite, molybdenite and in rare instances scheelite and wolframite. The ores are accompanied by dolomitic spar, talc, steatite and chlorite, occasionally by calcspar, quartz and fluorspar.

On the other hand, at Brosso, on the middle slope of the lower Dora Baltea valley, beds of magnesian limestone are mineralized by hematite and pyrite. This ore has, by reason of a pre-existing system of fault fractures, penetrated a longer distance than usual from the contact. It has been found that, wherever such a fissure cuts through a limestone bed, an orebody has been formed whose thickness decreases with the distance from the contact. These compact orebodies attain a diameter of 20 m. (65 ft.) or more and have a uniform strike. They consist of pyrrhotite and magnetite, with occasionally a little pyrite. These fissures, which continue into the diorite, also contain orebodies, but none that pay for working. The

[1] V. Sclopis and A. Bonacossa: *Monogr.* sulle miniere di Brosso (circond. d'Ivrea). Torino, 1900.

[2] V. Novarese: 'L'origine de giac. metallif. di Brosso e Traversella in Piemonte,' *Boll.* del R. Com. geol. 1901; No. 1, gives list of previous publications. 'Die Erzlagerst. von Brosso und Traversella,' *Zeit. f. Prak. Geol.*, 1902, pp. 179-187.

ores contain gold-bearing pyrite, marcasite, arsenopyrite, galena, copper pyrite and rarely zinc-blende, stibnite and bournonite, in a matrix of quartz and spathic iron stone.

At present the deposit near Brosso is the only one worked. It is worked for pyrite, which is used in the manufacture of sulphuric acid, the mean annual production being 25,000 tons.

7. *The Iron Ore Deposits of the Island of Elba*[1].

The iron ores of Elba are found only along the east coast of the island. The total known extent of the field is estimated by A. Fabri at 2,000 hectares, the deposits near Cape Calamita covering 1,130 hectares.

The ores consist of specular hematite, or of ordinary red hematite with limonite and magnetite at some points. The deposits form either sheeted masses, unquestionably superimposed on older strata, or irregular replace-

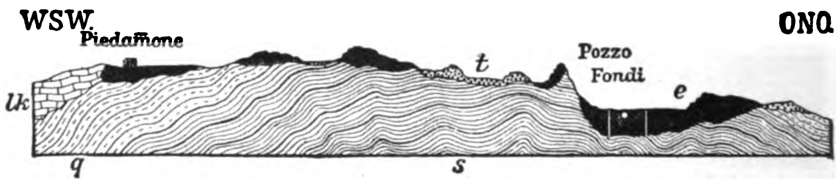


Fig. 244.—Section through the iron ore deposits of Rio. (Fabri.)
q, quartzite; s, sandstone and mica shale, of the Permian; lk, breccia-like limestone; e, iron ore; t, barren masses.

ments in the limestones, the latter deposits containing the minerals that elsewhere characterize contact metamorphic iron ore deposits.

The specular hematites at Rio Albano, Rio and Vigneria overlie Permian sandstones, quartzites and micaceous schists (Fig. 244), but are in turn overlain at some points by the limestone breccias of the Lower Lias. Sometimes, as at Pozzo Fondi, near Rio, the ores fill kettle-shaped depressions in the surface of the irregularly eroded Permian dolomites. Conversely, to the northwest of Rio the ores are seen to extend upward into the overlying calcareous breccias of Lower Liassic age, the upper limit being very irregular. It is probable that the depressions and hollows in the surface of the Permian now occupied by iron ore were originally filled by calcareous rocks. Finally, east of Rio Albano the Upper Liassic clay

[1] B. Lotti: 'Impressioni geol. di una breve gita all' isola d'Elba,' *Boll.* geol., 1876, Vol. VII. S. Czyszkowski: 'Régions ferrifères de l'île d'Elbe,' Alais, 1882. B. Lotti: 'Memorie descr. della carta geol. d'Italia' (Dell' Isola d'Elba), 1886, Cap. XIX, with full bibliography. B. Lotti: 'Sui depositi ferriferi dell' Elba,' etc., *Rass. Min.*, 1901, Vol. XIV, 4. A. Fabri: 'Relazione sulle miniere di ferro dell' isola d'Elba,' Roma, 1887.

slates are permeated by innumerable small veins of specular hematite. It is noteworthy that the iron ores of this region do not contain the admixtures of lime silicates characteristic of the southern fields. However, in the vicinity of the ore deposits, near Torre di Rio, there is an occurrence of pyroxene and epidote as a replacement deposit in a pre-Silurian calcareous slate.

A different state of affairs is found at Terranera, where the ore, mainlv specular hematite, fills the bottom of a small valley cut in a series of Silurian shales with calcareous intercalations. At Capobianco limonite and manganite fill depressions in a micaceous gneissoid schist, traversed by many granite dikes, and the orebody has branches running downward. On the coast near Capobianco a mass of tourmaline granite outcrops, and granitic dikes near Terranera show that there, too, plutonic masses may lie beneath the earth's surface.

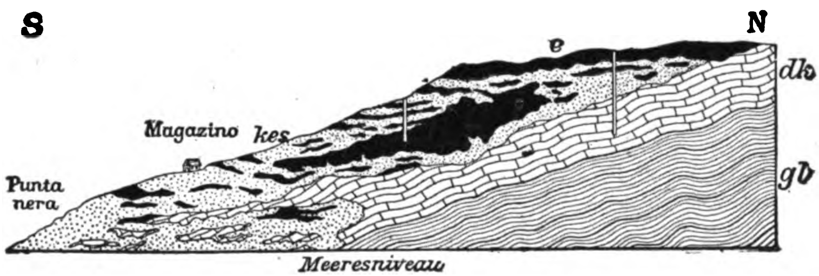


Fig. 245.—Section through the iron ore deposits of Calamita. (Fabri.) dk, crystalline dolomite; e, iron ore; kes, lime-iron-silicate rock.

Finally, in the Calamita area the iron occurs as hematite, limonite and magnetite, always accompanied by light-colored radial pyroxone, ilvaite (a hydrated calcium-iron silicate) and epidote, as well as garnet, opal and resinite (wax opal). Both the iron ores and the complex mixture of these other minerals are in every instance closely associated with crystalline dolomitic limestones, intercalated in mica schists and gneissoid schists of pre-Silurian age. The connection between iron ore, lime silicates and this limestone is shown in the section, Fig. 245. These facts leave no doubt that the limestone has been replaced by the ore and its accompaniments, a conclusion confirmed by the residual remnants of limestone lying in the midst of the mass of lime-silicate. Similar remarks apply to the deposits of Ginevro and Sassi Neri.

The similarity of the iron ore deposits of Elba to those of the Banat is so great that they, too, may be assumed to be genetically connected with deep-seated siliceous, igneous rocks. A direct contact with granitic rocks, to which the mineralization might be attributed, is, however, not shown at

Elba, as it is in the Banat region. It is surmised, however, that in the Elba iron district such plutonic masses may have initiated uprising mineral-bearing solutions, which not only mineralized the limestones, but also penetrated along the joints of non-calcareous strata. It can hardly be supposed that the solutions deposited their burden on the earth's surface, as might appear at first sight. As the tourmaline granite of Elba is intermediate in age between Eocene and Miocene it is reasonable to suppose that the iron ores, too, are of the same late period.

The technical value of the Elba iron ores varies greatly. On an average the ores contain the following percentages of iron: Rio Vigneria and Rio Albano, 60 to 66%; Terranera, 62 to 68%; Capobianco, 50%; Calamita, 54 to 63%; Ginevro, 60 to 63%.

The Capobianco ore also contains an average of 6% of manganese. The Elba iron ores are practically free from phosphorus, sulphur and copper. Only at two points do the ores contain an amount of phosphorus worth mentioning. Iron pyrite seldom forms a disturbing factor, and if copper ores occur, as at Calamita, they are easily picked out.

The wealth of Elba in iron ore was known in classical antiquity. Virgil, for example, mentions it in the Æneid. From the 11th century onward, detailed data containing the mining industry of the region are preserved. The mines belonged in succession to the republic of Pisa, the Prince of Piombino, France, Napoleon I, the Grand Duchy of Tuscany and finally, since 1881, to the Kingdom of Italy. Since 1880 the annual production of the iron mines is limited to 200,000 tons, although, according to Fabri's estimate in 1884, the stock then remaining amounted to 7,990,000 tons, so that it cannot be exhausted for a long time. In recent time, furnaces have been established on Elba itself.

8. *The Iron Ore Deposits of the Gora Magnitnaia.*

The Magnitnaia Mountains, which in the Atatsch rise to a height of 577 m. (1,890 ft.), are situated near the Ural river 65 km. (39 miles) south of Verhne Uralsk, on the low plateau which gradually passes into the flat Kirghese plain. The main mountain mass, according to J. Morozewicz,[1] consists of eruptive rocks of very diverse types. In general, augitic and amphibolic granites and diorites are intruded by younger syenites and augite-orthoclase-porphyries. These two groups are in turn intruded by dikes of quartz keratophyr and a cordierite-sillimanite-vitrophyre (atatschite). The augite feldspar rocks, usually much decomposed, are

[1] J. Morozewicz: 'Le Mont Magnitnaia et ses alentours,' *Mémoirs* du Comité Géologique, 1901, Vol. XVIII, No. 1, pp. 74-104; in Russian, with French résumé.

overlain on the lower mountain slopes by large and thick blocks of garnet rock, overlain in turn by deposits of magnetite, hematite and limonite, which altogether cover an area of about 2 square kilometers and attain a thickness of over 80 m. (262 ft.) The iron ore forms pockets, stocks and lump-shaped beds. It contains disseminated quartz and calcite, besides garnet, and the ore often alternates quite irregularly with a garnet epidote rock or with kaolinized masses. Besides the garnet rock, marble is found here and there, but normal Lower Carboniferous limestones are found only far away in the environs of the mountains and concealed by Pleistocene deposits. These structural and geological conditions resemble those in the Banat iron deposits so closely that those of Magnitnaia are placed next to the Banat in this work. Morozewicz, however, does not claim a contact metamorphic genesis, but on the contrary tries to prove a purely hydrochemic origin. According to him the weathering of the eruptive rocks altered the augite to garnet, which in turn on further decomposition gave epidote, chlorite, magnetite, hematite, quartz and calcite. It is well known, however, that the usual process of weathering of such eruptive rocks does not take place in this way. Moreover, the garnet rocks and ore masses are far too extensively developed to be explainable as the result of merely superficial weathering.

9. *The Copper Deposits of Miednorudiansk, Near Nizhnyi Tagilsk.*

Although the geology of this ore deposit, formerly famous for its great wealth, is as yet not known in detail, all the existing descriptions[1] show that the copper deposits are the result of a concentration effected mainly by metasomatic processes in the contact region about plutonic masses.

Miednorudiansk lies immediately south of the Vysokaya Gora (central Ural), whose magnetic iron ores contain interspersed copper sulphides, as mentioned previously. The copper deposits lie between two belts of fossiliferous Devonian limestone, in a rock mass formed of brecciated calcareous porphyrite-diabase tuffs and much altered green schists having north-northwest trend. A zone of limonite and ferruginous clay extends the entire length of the range. This belt has yielded great quantities of oxidic copper

[1] P. Jérémées: 'Observations sur les gîtes cuprifères du versant et de la chaine de l'Oural,' in Russian, *Journ.* d. mines, 1859, Vol. IV, p. 76. H. Müller: '(Vortrag im bergm. Verein zu Freiberg.)' *Berg. u. Hütten Zeit.*, 1866, No. 22. Gr. Mayer: 'Ueber die Kupfererzlagerstätte Mednorudjansk am Ural,' *Oesterr. Z.*, 1877, No. 36, 37. A. Karpinsky: 'Aperçu des richesses minér. de la Russie d'Europe,' 1878. P. Gladki: 'Chemische-geol. Bemerkungen über die Erzlagerstätten Mednorudjansk und Wyssokaja Gora' (in Russian), *Journ.* d. mines, 1888, Vol. I, pp. 96-123. Th. Tschernyschew: *Guide* du 7th Congrès Géol. Intern., 1897, Vol. IX, p. 11. E. S. Fedorow: 'Ueber Mednorudjansk,' *Mitth.* des Verbandes der russ. Berging (in Russian), St. Petersburg, 1900.

ore and in depth contains copper pyrite, bornite and copper glance. Besides the malachite, for which the mine is famous, the iron-charged clays also contained azurite, tagilite, asperolite, brochantite, libethenite, chrysocolla, demidowite, melaconite, cuprite, native copper, etc. The greatest accumulations of ore were found where the clayey masses were in contact with the limestones. The latter in many cases appeared corroded into a spongy mass, which sometimes carried fossils that were readily detachable. In the northern part of the mineralized area, at the Avrorinsky shaft and in the Svernaya shafts, bodies of magnetic iron ore containing copper ores disseminated through the mass are found at the contact of the western limestone zone. This combination of magnetic iron ore with copper sulphides, together with the widespread occurrence of partly epidotized pyroxene garnet rock in the Miednorudiansk mines, suggests that these ore concentrations are within an eruptive contact zone.

Formerly H. Müller[1] thought that a copper-bearing diorite rock existed in depth, which by its decomposition had furnished the iron-charged clays with the copper oxides. Hence he described the deposit as analogous to that of Gumeshevsk (see page 601). This, however, does not seem to have been confirmed by later studies.

E. S. Fedorow[2] has recently shown the almost complete absence of a primary eruptive feldspathic rock. It is, however, possible that at still greater depth there are the syenites and orthoclase porphyries of the neighboring Vysokaya, which form the real generators of ore. This seems to be indicated by the dike of what is presumably augite porphyry, recorded by the last named author.

The Miednorudiansk mine has yielded most of the malachite worked up into objects of art in the Imperial stone-polishing works, one huge block weighing 328 tons being found in 1836 at a depth of 70 to 80 m. The ores at this mine average 2.3%, with an annual production of 1,240 tons of copper (DeLaunay). From 1814 to 1877, 2,600,000 tons of ore were produced.

The Bogoslavsk copper mines, situated much further north, on the east side of the mountains, exhibit quite similar geologic conditions, as shown by Müller, E. S. Fedorow and recently by Usspenski[3], who shows that the orebodies are intimately associated with the augite-garnet rocks found where Lower Devonian limestones are cut by hornblende granite and porphyries. Later porphyry dikes cut and displace the orebodies.

[1] H. Müller: *Berg u. Hütten. Zeit.*, 1866, p. 160.

[2] E. S. Fedorow and W. W. Nikitin: 'Das Bergrevier von Bogoslowsk,' St. Petersburg, 1901. With many plates, sections, etc., and bibliography (in Russian).

[3] Usspenski II: 'Die Eisenerzlagerstätten im Bergbezirk Bogoslowsk,' *Berg Journal*, IV., St. Petersburg, Nov., 1900, in Russian.

10. *The Copper Ore Deposits of Gumeshevsk.*

Gumeshevsk lies seven and a half miles southwest of Ekaterinburg, on the west slope of the Ural. According to H. Müller[1] a belt of marmorized limestone, intercalated between crystalline schists, is cut lengthwise by a dike of diorite, dipping from 40 to 50° east, and having a thickness of 50 to 60 m. (164 to 196 ft.) At the contacts on each side there are ocher yellow, iron-charged clays, the products of subsequent decomposition of the rocks. This clay occasionally reaches a thickness of 200 m. (650 ft.) in outcrop, but wedges out below. Moreover, the garnet rocks seem to belong to the contact. The ores are found partly in nests of iron pyrite and copper pyrite in the diorite of the lower portions of the deposit, but mainly in the earthy clays as malachite, chrysocolla, cuprite, azurite, earthy red oxide of copper, and brochantite. A malachite block weighing 2,800 kilograms was found in this deposit at a depth of 36 m. below the surface, a part of it being now in the museum of the Mining Institute at St. Petersburg. The ores mined contained on an average 3% to 4% copper. The mines are now abandoned. Quite similar conditions prevail, according to H. Müller, in the deposits of Soimonovsk, five miles southwest of Kyschtim.

11. *The Copper and Lead Ore Deposits in the Campiglia Marittima, Italy*[2].

In the Campiglia Marittima, in the coastal plain of Tuscany, 35 miles southeast of Leghorn, a metamorphic marble (Lower Liassic) is cut by peculiar eruptive dikes which are regarded by some authors as quartz porphyry, by others as liparite, the rocks occurring in part in the form of mixed dikes. The latter feature is characteristic of the Temperino dike, which holds an important ore deposit. This dike has a north-northwest strike, and runs southwest of Monte Calvia, which overtops the region.

The Temperino vein, attaining a thickness of 20 m. (65 ft.), as exposed in the Cava Grande and some other mines, consists, near the point first mentioned, mainly of a cordierite bearing liparite, or quartz porphyry. In

[1] H. Müller: 'Kupfererzlagerstätten von Gumeschewsk und Soimonowsk am Ural,' *Berg u. Hutten. Zeit.*, 1866, No. 29, p. 252.

[2] P. Savi: 'Abbozo de carta geologica de provincia Pisana,' 1863. F. Hoffmann: 'Geogn. Beobachtungen auf einer Reise durch Italien und Sicilien,' Karsten's Archiv, Vol. XIII, pp. 24-29. A. Burat: 'Théorie des gîtes métallifères,' etc. Paris, 1845, p. 208. G. vom Rath: 'Geognostisch-mineralogische Fragmente aus Italien,' II, part No. 7. 'Die Berge der Campiglia in der Toskanischen Maremne,' Z. d. D. G.-G., 1868, Vol. XX, p. 307 *et seq.* B. Lotti: 'Le roccie eruttive feldspatiche di Campigl[illegible] Marittima,' *Boll.* del R. Comit. Geologico, 1887, Nos. 1 and 2. Also 'Sulla Gen[illegible] dei giacimenti, etc.,' *Boll.* geol. 1900. No. 4, with bibliography.

the middle it is much more basic and may be described as an augite porphyry showing rather sharp boundaries against the quartz porphyry on both sides. At other points, as in the Coquand shaft, one band of quartz porphyry is lacking, and thus the cross-section loses its symmetry. In all cases, however, a very remarkable mass of ore-bearing rock is found at the contact of this mixed vein and the Liassic limestone, which is there completely crystalline. The ore-bearing mass consists of a radiating, dark green iron-lime-manganese augite and a greenish-gray or reddish manganese lime augite, as well as ilvaite (a lievrite). The augite occurs in radial fibers forming round masses and is permeated by black ilvaite. The ores are intimately connected with these silicates, and consist most frequently of chalcopyrite, iron pyrite or less commonly of galena and brown zinc-blende, together with some arsenopyrite, all of which are sometimes accompanied by quartz and calcspar. The ores appear either as cores of the spherical augite concretions or lie between the radiating needles of augite. Stringers of the ore-bearing augite mass branch off toward the adjoining marble. According to Bergeat[1] fluorite also occurs.

Northeast of the Temperino vein, in the direction of Monte Calvi, there is a parallel vein of similar composition which has been worked in the Cava del Piombo and some other mines. In the Cava del Piombo, east of Castello San Silvestro, it is about 20 m. thick. Its ore-bearing part consists of radial augite spheroids up to 2.4 m. in diameter, which contain cores of the above named metallic sulphides. Moreover, from this nucleus of ore radiating stringers of ore extend outward and sometimes the augite spheres are encrusted by thin layers of ore. The spaces between the augite nodules are filled with an irregular, granular-fibrous mass of augite with large quartz druses.

The genesis of these deposits is as yet quite a puzzle. As, however, the peculiar radial augite aggregates seem to have been formed as a sequel to a contact action between an eruptive magma and Liassic limestone, and as the ores evidently represent segregations formed simultaneously with the augite, the deposit has been placed in the class of contact metamorphic deposits. It seems, however, to correspond more closely in its genesis to that of the tourmalinized and auriferous rocks of and about several granite areas.

Copper and lead mining in the Campiglia Marittima seems to date back to Etruscan times. The mines were actively worked in the days of the Medici, and were reopened on the two veins about the beginning of the 19th century.

[1] 'Beiträge zur Kenntniss der Erzlagerstätten von Campiglia Marittima,' N. J. f. M., 1901, part I, p. 135.

12. *The Silver Lead Deposits of Sala, in Sweden*[1].

The mines lie 2.5 kilometers southwest of Sala, in Westmanland. While the town itself is built on a flat cultivated plain, the ground of the mining region rises in low, often rocky hills. An area 10 km. long and up to 3.6 km. wide is covered by a granular crystalline, dolomitic limestone, striking northnortheast-southsouthwest, abutting on the west against fine-grained flaky biotite gneisses and 'hälleflinta,' while on the east it is cut off by hornblende granite. In one of the limestone quarries the rock is seen to be traversed by a diabase dike 0.36 m. thick, several times faulted, and this feature has been repeatedly encountered in the mines. The most striking feature about these mines is the great cave-in, formed in olden times by the collapse of extensive excavations. On the bottom of this basin the work has been resumed, the deposit being worked at the present time for zinc-blende, whereas formerly only the argentiferous galena

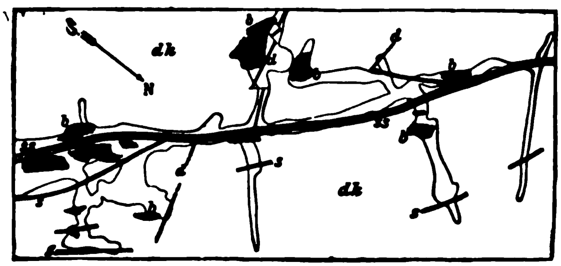


Fig. 246.—Plan of the 190 m. level of the Sala Mine.
dt, dolomitic limestone; s, skolar; ss, stor sköl; d, diabase; b, galena.

was extracted. On one of the walls of this cave-in, the Stor Sköl (literally, large shell, meaning main fissure) is at present well exposed, consisting of a zone of friction breccia 3.5 m. thick, which passes through the dolomite limestone with a dip of 60° west. This Sköl consists of completely crushed country rock, traversed by slip planes and permeated by stringers of calc-spar, chlorite and talc segregations, and also carrying layers of zinc-blende that lie parallel to the walls.

Further information is afforded by the underground workings (all in the limestone), which lie on both sides of the Stor Sköl, and show it to run nearly south, and to be usually 1 to 3 m., rarely as much as 10 m. wide.

[1] Important publications: W. Hisinger: 'Versuch einer mineralogischen Geographie von Schweden,' Translation by F. Wöhler, 1826, pp. 124-133. B. v. Cotta: 'Lagerstätten II,' 1861, p. 528. O. Gumaelius: 'Sveriges Geol. Undersökn,' Bladet Sala, 1868. Also 'Om trappskölen i Sala grufva,' *Geol. Fören Förh.*, I, 1872-1874, pp. 162-166. Fuchs and De Launay: 'Traité,' 1892, Vol. II, p. 611.

In the course of many years of mining the work has exposed numerous narrow side fissures, spurs from the main fissure, as well as a number of parallel fractures, whose arrangement may be gathered from the ground plan of a part of the 190 m. level shown in Fig. 246. This also shows how the diabase dike above mentioned is displaced by the Stor Sköl.

Only a small amount of ore is found within the skölar, and this is seldom workable. On the contrary the ore occurs mainly as impregnations and as a network of stringers in the midst of the dolomitic limestone near the skölar, as is also shown in Fig. 246. The richest orebodies have been worked along the Stor Sköl. Their boundaries are naturally not sharp, the ore-bearing rock passing quite gradually into barren limestone. The orebodies are frequently separated from the Sköl by a barren, or at any rate a very poor zone lying between the Sköl and the exploited masses.

The main ore minerals at Salberg are argentiferous galena and brown or yellow zinc-blende. The two as a rule are not commingled, but occur in separate orebodies. Toward the west the zinc-blende predominates. The lead ore contains 3% to 4% lead, which in turn contains 0.70% silver (Fuchs and De Launay). Associated with these two ores are also found iron pyrite, arsenopyrite, stibnite, rarely also copper pyrite and two varieties of silver amalgam with 50% and 75% silver respectively. According to Hj. Sjögren, a part of the silver is present as silver glance. Sometimes the galena is intimately intermingled with magnetite. This rare association becomes more intelligible when it is remembered that, besides the orebodies of the Salberg mine, the crystalline limestone contains large beds of magnetic iron ore, which have in fact been worked. Among the still rarer ore minerals at Salberg, mention must be made of pyrrhotite, native silver, ruby silver, tetrahedrite, native antimony, boulangerite and cinnabar.

Furthermore, the crystalline dolomitic limestone in the vicinity of the orebodies often contains various silicates, sometimes constituting entire beds with schistose structure, in which case they may also be impregnated with ore. Among these silicates, the most frequent are talc, chlorite, serpentine, actinolite, and melacolite. Broken crystals of salite, recemented by galena, have been found and a blackish garnet, a potassium feldspar and a heavy tourmaline occur rarely in the mixture. Spherical radial aggregates of black or bluish translucent tourmaline formerly occurred there, together with fibers of salite, in the midst of coarsely crystalline calcspar. Barite, too, is mentioned.

Hisinger long ago recognized that the Salberg deposits are impregnations of the limestone by material which has come from the Skölar. The presence of the garnet, salite and tourmaline suggests contact metamorphism of the limestone by the neighboring granite, and there is a further probability that the mineralization of the limestone, too, proceeded from the Skölar, simultaneously with this contact metamorphism.

According to existing records, which date back to 1512, the mines of Sala were already worked during the reign of Sten Sture. According to tradition, however, the government mined for silver ore at a much earlier date, mainly during the reign of Magnus Ladulås (1249-1290).

The works were especially productive at the time of Gustavus Adolphus. From 1500 to 1800 the mines yielded a total profit of 1,600,000 Swedish marks, from 1800 to 1868 about 200,000 marks.

13. *Gold-Bearing Contact Metamorphic Deposits in Montana.*

A monograph by W. H. Weed[1] describes a very peculiar contact-metamorphic deposit in the Elkhorn region, Montana. This lies about 20 miles northeast of Butte (see page 223) on the eastern border of a great mass of granite, the Boulder Batholith, which is of Tertiary age. The ores occur in upturned and steeply dipping Paleozoic strata.

Of the many lesser properties, the Dolcoath is the most interesting. The ore deposit of the Dolcoath mine is a granular crystalline bed of garnet, diopside and calcite, which contains auriferous tetradymite and bismuthinite, as well as free gold.

On the higher slopes of Elkhorn peak, great masses of marble ¼ mile long and 100 feet thick occur included in the midst of andesite. The lower layers of this marble are composed of granular, garnetiferous magnetites.

As a supplement to the deposits described on page 539, mention may also be made here of an ore deposit of former economic importance, that of the Elkhorn mine proper, which is instructive in many respects. The orebody of this mine is of irregular shape and composed mainly of argentiferous and auriferous pyrite-blende lead ores. There are two classes of ores. The first is quartz carrying rich silver sulphides and a little pyrite. This dry ore is found along the shale-limestone contact. The second variety of ore consists mainly of argentiferous galena, argentiferous, light-colored, brown and blackish blende and pyrite. The orebodies form two rich shoots beneath an arch of altered shale, either along its contact with the crystallized dolomite, or as great stocks of silver-lead ore enclosed in the dolomite. These orebodies are situated in the crushed dolomite forming the saddle of anticlinal folds. The anticlinal 'saddles,' which in part have been broken up into a breccia, lie beneath a rather impervious cover of altered shale

[1] W. H. Weed: 'Elkhorn Mining District,' 22d *Ann. Rep.* U. S. Geol. Survey, Washington, 1902.

(hornfels), which is also folded. The crushed rock served as a channel for solutions rising from the depths, the axis of the folds having an oblique inclination. Thus the Elkhorn mine is a good example of the influence of folding on the development of metasomatic ore deposits. The mine just named showed from 1875 to 1899 the splendid production of 264,350 kilograms (8,902,000 oz.) of silver and 264 kilograms (8,500 oz.) of gold.

A large number of contact-metamorphic deposits of North America, in part carrying gold and silver ores, are adequately described by Lindgren[1] and Weed.[2]

The Bannock, Mont., example, with gold and gold tellurides in garnet rocks, has already been noted (p. 578).

14. *Contact Deposits of Asia and America.*

At Balia Maden, in Asia Minor, about 160 km. north of Smyrna, ore deposits[3] of considerable size are found at the contact between Carboniferous limestone and augite andesite. Along the contact in a zone 2 to 4 m. broad, the andesite is impregnated with quartz and ore, while the limestone, which contains epidote, garnet, anorthite and quartz, and is of superior hardness, encloses a number of irregularly columnar orebodies. These consist of argentiferous galena, together with zinc-blende, pyrite, copper pyrite and tennantite, also smithsonite and cerussite. They are closely connected with fissures running approximately parallel to the contact plane.

These mines, whose history extends back to the time of Pericles, have in recent times produced about 3,000 tons of lead annually. This contains 0.18% of silver, which is extracted locally. There is also an annual exportation of 7,000 tons of ore with 70% lead and 0.13% silver, as well as 4,000 tons of blende, some 100 tons of cadmia and a little copper ore.

At Tres Puntas, in the province of Atacama, Chile, the Mesozoic limestone has been changed, near intrusions of quartz porphyries or liparites, into a garnet rock containing copper ores. Similarly, at the Cerro de Campana in the province of Valparaiso, the Mesozoic limestone is altered at the contact with diorite and contains garnet with bornite and free gold (W. Moricke). The Seven Devils copper deposits of Idaho are similar (W.

[1] W. Lindgren: 'The Character and Genesis of Certain Contact Deposits.' *Trans.* Am. Inst. Min. Eng., February, 1901.

[2] 'Ore Deposits near Igneous Contacts.' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Bukowski: 'Die geol. Verhältnisse der Umgebung von Balia Maden.' *Sitzungsber.* d. K. Ak. d. W. in Vienna, math.-phys. class, Vol. CI, part I, February, 1892. K. Weiss: 'Lagerstätten im westlichen Anatolien.' *Zeit. f. Prak. Geol.*, 1901, No. 7. G. Berg: 'Beiträge zur K. von Balia-Maden.' *Zeit. f. Prak. Geol.*, 1901, p. 365. A. Κορδελλα. 'Ο μεταλλεύτικος πλοῦτος τῆς 'Ελλάδος. 'Εν' Αθήναις, 1892, Σ 64.

Lindgren[1]). Such deposits are common in Mexico[2], and extensive ore-bodies of this character are found accompanying deposits of another type at Clifton and Globe, Arizona.

In Queensland, according to G. Wolff[3], limestones at the contact with granite contain gold-copper ores, garnet, wollastonite and quartz.

The important deposits of iron ore found in the Tayeh district on Yangtse river in China, too, seem to be typical contact formations. According to G. Leinung[4], they occur at the boundary between sedimentary limestone and a diorite massif over a distance of about 15 km. with an average thickness of 75 m. They consist of hematite, red hematite, and magnetite, almost without gangue, and are on the whole poor in phosphoric acid.

D. ORE-FILLED CAVITIES IN ROCKS.

1. *Nodular Iron Ore.*

In several of the limestone ranges of central Europe, such as the Southern Black Forest, the Franconian Jura, the Alps of Tyrol, Carinthia and Carniola, and the Swiss and French Jura, the rocks show irregular chambers and enlarged fissures, which extend downward to a moderate depth. These spaces have the shape of irregular and often branching funnels, kettleholes, pipes or tubes, and contain hematite nodules enveloped in clay. These corrosion cavities occur mainly in the limestone and dolomite of the Jura, but sometimes in Triassic and Cretaceous limestone. The cavity walls have been etched smooth by the water and often appear as if varnished, especially when somewhat silicified. Sometimes they are also coated with a crust of brown hematite. When prongs occur some of them may be empty. The filling of the cavities is exceedingly varied. It consists mainly of limestone débris with red earth or clay, such as is so apt to be left as a residue from the solution of limestone. Besides this clay we find, together with the iron ore, various kinds of drift material, sand and clay washed in from above, and even streaks of lignite.

The age of this alluvial material may be determined by the organic remains frequently found with the ore. Teeth and bones of Oligocene mammals, such as anoplotherium, palæotherium and lophiodon and others of Miocene age, such as mastodon, rhinoceros and dinotherium, and Tertiary

[1] W. Lindgren: 'Character and Genesis of Certain Contact Deposits,' *Trans.* Am. Inst. Min. Eng., 1901.

[2] Aguilera: 'Geographical and Geological Distribution of the Mineral Deposits of Mexico,' *Trans.* Am. Inst. Min. Eng., Mexican volume, 1903. See also W. H. Weed: 'Ore Deposits near Igneous Rocks,' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Wolff: 'Das Australische Gold,' *Zeit.* d. D. G. Ges., 1877, p. 149.

[4] G. Leinung: 'Bericht über das Eisenerzvorkommen im Tayeh-Bezirk, Provinz Hupeh.' Siegen, 1896.

plant remains are found, so that the introduction of the ore must certainly have taken place in the Tertiary.

Where such cavities occur in a basin of a limestone area, their filling is sometimes directly connected with superficial ore deposits of the same age. The latter are often of considerable thickness, as much as 30 meters (98 ft.). Most ores of this kind are considered to be deposits from iron-bearing springs and the hematite nodules in particular are regarded as concretions formed from such spring waters. This hypothesis may be

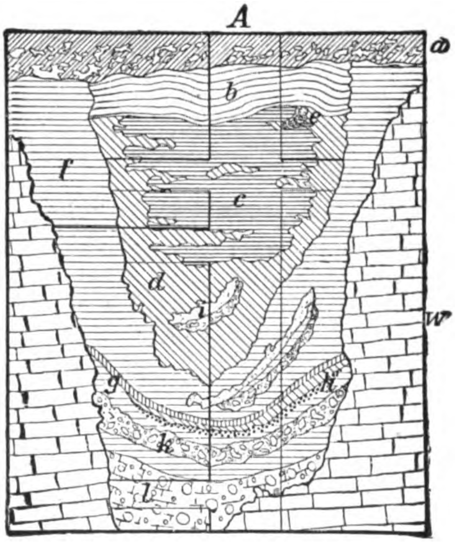


Fig. 247.—Section of a low-grade pocket of nodular ore. Ludwigsthal. (J. von Mandelsloh.)
a, Fragments of Jura limestone; b, blue and brown clay; c, lignite; d, clay with plant remains; e, chalky limestone masses; f, yellow clay; g, brown clay with lignite; h, bean ore; i, sandstone; k, quartz conglomerate; l, limestone conglomerate; w, limestone and dolomite of white Jura.

true in most cases, but not in all. As proved by Stelzner[1], the nodules of pisolite ores of the Villacher Alpe in Carinthia show no indication of a radial or concentric shelly structure, but appear to be fragments of brown hematite formed elsewhere and washed into the cavities, after having been rolled in water. In fact, these Carinthian nodular ore pockets, which are in a great bed of Triassic dolomite, contain red earth in which there are masses and ore nodules formed of quartz grains, zircons, rutiles, garnets, tourmalines, splinters of epidote and hornblende, the material being the residue of crystalline rocks destroyed elsewhere on the earth's surface.

[1] A. W. Stelzner: 'Ueber die Bohnerze der Villacher Alpe.' *Verh.* d. k. k. geol. Reichsanst., 1887, p. 219.

The deposits mentioned below are the most important examples of this class, but at present no ore deposits of this kind, *i. e.* as fillings of open pits, are anywhere of great importance.

Many funnel-shaped deposits of this kind were formerly worked in the Suabian Alps, supplying the local iron furnaces. A section of one of these Suabian pockets of nodular ore[1] which held, however, only a small amount of iron ore, is quite interesting on account of the great variety of the inclusions, and is reproduced in Fig. 247. The nodular ore of this region is found in cavities in the Franconian dolomite (upper white Jura), which forms the surface of extensive plateaus. Mention may also here be made of the re-

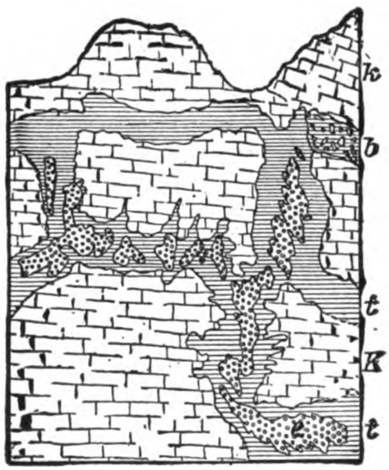


Fig. 248.—Cross-section of the old nodular ore mine near Roeschentz. (Gressly.) l, limestone (white Jura); t, clay; b, limestone breccia; e, nodular ore.

markable discovery of the teeth of an anthropoid ape in a deposit of nodular ore in the Suabian Alps, described by W. Branco.[2]

A second well-known German occurrence of nodular ore is in the Jura district, of the southern part of Baden. According to the older descriptions, however, the ore occurred not as the fillings of cavities, but as a surface formation of considerable horizontal extent, lying either on the white Jura, or more rarely on the Muschelkalk, being in part concealed by alluvial débris. The 70 or 80 mines once in operation have been idle since the beginning of the 1860 decade. At this place the ore-bearing layers alternated with those of sand, limestone conglomerate and drift. Besides the ore, there

[1] Graf F. v. Mandelsloh: 'Geogn. Profile der schwäbischen Alp,' 1834.

[2] Branco: 'Die menschenähnlichen Zähne aus dem Bohnerz der schwäbischen Alp.' Stuttgart, 1898.

was also found jasper in the form of nodules, whose concentric layers enclosed druses of calcspar, gypsum or quartz. A distinction was made between pure ore (Reinerz) and pisolite ore proper (Bohnerz). The former is an earthy lamellar or compact or fibrous iron ore, occurring either in patches, or in the form of kidneys and nodular concretions up to 2 ft. thick. The center of the kidney-shaped formations is either earthy or is hollow and lined with hematite incrustations, fibrous limonite, crystals of brown spar, siderite or calcite. The 'bean' ore consists of concentric concretions of brown hematite varying from the size of a pea to that of a walnut, and forming a continuous series of nests and beds. The associated mammalian remains and sharks' teeth found in the deposits show that the ores were deposited in Tertiary time. Whether the limonite concretions and jasper nodules were secreted in place or come from disintegrated Jurassic rocks does not seem to have been determined with certainty.

Similar deposits are very widely distributed in the Swiss and French Jura, for example in the region of Laufen and Roeschentz in Switzerland. The multiform ore concretions lie in variegated, red or yellow clays, within irregularly branching cavities. Masses of nodular ore occur both above and in part concealed in the cavities. At Roeschentz such cavities when opened by small shafts were found to be connected in depth with irregular horizontal cavities also containing workable ore. A description by Gressly[1], whose conclusions are altogether opposed to the views presented here, gives important details of the exposures disclosed by mining operations. The cross-section, Fig. 248, is from this work.

[1] A. Gressly: 'Sur le Jura Soleurois.' *Neue Denkschriften.* Neuchâtel, 1841, Vol. V, pp. 245–349.

DETRITAL DEPOSITS.

By detrital deposits we understand accumulations of ore formed by the destruction and redeposition of primary deposits. These two results have been accomplished, in the main, in a mechanical, but in part, also, in a chemical way. In both cases water was the main agent used by nature for the purpose. Such a destruction and redeposition of primary deposits may have taken place in remote geologic periods, but only in comparatively rare cases have the products of such periods been transmitted to us in a recognizable condition. On the other hand, the Tertiary and Pleistocene formations of the earth's surface contain a great number of such detrital deposits, as they are commonly called. It is customary to use the term placer gravels for the Pleistocene and Tertiary alluvial gravel deposits, but this term is not extended to older deposits of this kind, though they may be completcly equivalent to them genetically; at most they are called 'fossil placers.'

A. OLDER DETRITAL DEPOSITS.

I. DETRITAL DEPOSITS OF IRON ORE.

I. Detrital Deposits of Limonite in the Cretaceous Formations.

(A) In Lower Cretaceous Rocks.

The Iron Ore of Salzgitter and of Dörnten, North of Goslar.

These deposits, which are of considerable economic importance, occur in a range of hills formed by a steep, narrow, northwest-southeast anticline of Neocomian, Jurassic and Triassic strata, the ore bed outcropping along the flanks of the anticline in two approximately parallel zones.

The Salzgitter deposit is a distinctly stratified bed 3 to 25 m. thick, consisting of rounded or angular fragments of limonite, with some phosphate nodules, bound together by a ferruginous and in part somewhat silicious cement poor in lime. The fragments come from the Middle and Lower Dogger, the Lias, Keuper, Muschelkalk and Bunter sandstone. Worn Liassic ammonites are quite common in these masses. That the deposition of the hematite pebbles took place in Neocomian time is proved by the presence of the characteristic cephalopods of that age, enclosed in the ore bed, especially species of *Perisphinctes* and *Olcostephanus,* and further southward also *Belemnites subquadratus* Röm. These ores are underlain to the north by a great variety of Triassic and Jurassic strata. The ore beds are overlain by various strata ranging from the middle Gault to the Minimus clays of the upper Gault. From these facts it is inferred that the deposit was formed by the destruction, elaboration and partial re-deposition of the Jurassic and Triassic beds. It is a shore deposit formed by the transgressing sea of the Older Cretaceous, in which the ironstones, originally scantily distributed throughout the most diverse older horizons, were concentrated as a result of their hardness and weight.

The chemical composition of the Salzgitter ores is shown by the following analyses:

	I.	II.	III.
SiO_2	19.32%	19.73%	19.66%
Fe_2O_3	52.09 "	52.79 "	52.66 "
Mn_2O_3	1.07 "	0.57 "	1.15 "
Al_2O_3	4.36 "	3.55 "	4.68 "
CaO	5.27 "	4.47 "	7.54 "
P_2O_5	1.67 "	0.99 "	1.73 "
H_2O and CO_2 (combined)	12.21 "	11.63 "	13.01 "
H_2O (hygroscopic)	4.00 "	5.28 "	
Fe	36.46 "	36.96 "	36.86 "
Mn	0.75 "	0.40 "	0.80 "
P	0.73 "	0.42 "	0.76 "

According to R. Boettger, some samples of the ironstone of Salzgitter contain vanadium. Mining on a large scale began about the middle of the 19th century. The northern mines, and the Fortuna among the southern, are now abandoned. The Georg Friedrich mine, near Dörnten, belonging to the Ilsede furnace, on the contrary, is still active.

(B) In Upper Cretaceous Rocks.

1. *The Iron Ores of Ilsede.*[1]

Iron ore deposits that have been worked since 1860 occur in Hanover, near Ilsede. These deposits form a bed intercalated in the Senonian chalk.

1. Between Adenstedt and Gross-Bülten 2.5 k. (1½ miles) west of Ilsede, there is a bed 8 to 9 m. (26.2-29.5 ft.) thick opened to a length of 4 km. (2.4 miles) on the strike. 2. Between Lengede and Bodenstedt, 10 km. (6 miles) southwest of the Ilsede furnace, a bed 2.2-7 m. (7-22 ft.) thick is worked, and has been followed to a distance of 2.1 km. (1.26 miles)

[1] A. v. Strombeck: 'Ueber die Eisensteinablagerung bei Peine.' *Zeit.* d. D. G. G., 1857, Vol. IX, pp. 313–322. D. A. Brauns: 'Ueber die obere Kreide von Ilsede bei Peine,' etc. *Verh.* d. naturh. Vereins zu Bonn., Vol. XXXI. Also, 'Ueber das Eisensteinlager von Ilsede,' *Z.* f. d. ges. Naturw. zu Halle, XLIII, p. 280. Mr. Hoyer has furnished the notes for the summary here given.

along the strike. At both mines the ore bed, with its underlying and overlying strata, is actually the greatly depressed, much fissured flank of an anticline, whose opposite flank has, for the most part, been removed by denudation. Remnants of the bed in the drift of Hohenhameln and Hoheneggelsen, as well as of Ilsede, and other facts indicate a former much greater extension southward.

Reference to the Senonian is substantiated by the fossils present in abundance in the cement of the detrital deposit, such as *Ostrea diluviana* Sow., *Janira quadricostata* Sow., *Terebratulina striata* d'Orb., *Belemnitella quadrata* d'Orb., as well as by ammonites up to 95 centimeters in size, of the subgenus *Placenticeras*. In the overlying strata, moreover, where they have not been removed by denudation, the typical Senonian everywhere follows, but the stratigraphic relations indicate that the ore was deposited transgressively on various older limestone strata.

The ore consists of fragments of brown hematite of globular to ellipsoid shape, varying in size from that of a nut to that of a fist. The pieces are mostly angular and sharp-edged, but some of them have been rolled; they are cemented by a yellowish-brown marl or earthy limonite. Some of the cobbles are hollow geodes whose walls show a well marked crust structure and whose interior frequently contains druses of pyrolusite, psilomelane, calcspar and rhodochrosite.

The brown hematite fragments as well as the phosphate nodules which not infrequently accompany them are derived from the erosion of beds belonging to the Gault, for they often enclose remains of *Acanthoceras Millettianum* d'Orb., and *A. Cornelianum* d'Orb., fossils characteristic of the Gault of this region. These fragments represent the most resistant parts of the destroyed Gault strata assorted by the transgressing sea. On the other hand, no Jurassic remnants were found in them. From what has been said, it appears that the term pisolitic ores (Bohnerze), sometimes used for these ores, is entirely inappropriate.

Manifestly the chemical composition of a formation of this kind must vary greatly, so that only an average analysis is of technical value. For the Ilsede iron ores it is as follows:

Fe	34.8%
Mn	3.9 "
SiO_2	6.6 "
Al_2O_3	3.4 "
$CaCO_3$	10.0 "
P	1.1 "
S, MgO	Traces.

The production of the iron mines of the Peine district for 1898 was 516,225 tons.

Entirely analogous but smaller deposits are known at the **Gehrdener** Berg, near Hanover.

2. *Tertiary Alluvial Deposits of Magnetite and Red Hematite of the Banat, Hungary.*

A deposit of this class occurs on the broad mountain ridge of Pojana Wertop, 4 km. (2.4 miles) south of Bagschan in southern Hungary. It consists of Tertiary stream gravels, which rest on crystalline limestone belonging to the crystalline schists. The gravel consists of the typical rocks of the Dognacska-Moravicza mineral zone (page 590), viz., crystalline limestone, garnet rock, magnetite and hematite, besides various crystalline schists, banatites and other rocks. Both magnetite and hematite occur in rounded pebbles and blocks sometimes weighing as much as 7 to 8 tons, the ore being mainly concentrated in the deepest layers of the gravels. The gravel beds are in places 164 feet (50 m.) thick. The ores are extracted by open cuts, all material above 0.16 feet in diameter being saved. The ore constitutes from 20 to 33⅓ % of the mass. In 1894 the locality yielded 4,100 tons of ore.

II. Ancient Deposits of Gold-Bearing Gravels.

1. *The Gold-Bearing Cambrian Conglomerates of the Black Hills in Dakota.*

The 'cement' deposits of the basal conglomerates of the Cambrian beds of the Black Hills are, according to Devereux[1] and Irving, fossil gravels. At the base of a series of Cambrian rocks that rest directly upon upturned schists there is generally a bed of gravel, which in the vicinity of the Homestake lode is gold-bearing and has yielded heavily[2]. The conglomerate is usually 3 to 4 ft. thick and grades upward into a hard, dense quartzite. The auriferous portion occupies irregular depressions in the old schist surface, and was probably not uniformly distributed over the old shore line. The gravel is composed of rounded waterworn fragments of schist, the gold-bearing portions being cemented by oxide of iron or pyrite. The gold is rounded, worn by attrition and concentrated on the bed-rock. According to Irving it was derived from gold-bearing Algonkian schists. There is also in places an enrichment due to ferric sulphate solutions and possibly to the intro-

[1] W. B. Devereux: 'The Occurrence of Gold in the Black Hills,' *Trans.* Am. Inst. Min. Eng., 1882, Vol. X, p. 465. F.C.Smith: 'The Potsdam Gold Ores of Black Hill,' *idem*, 1898, Vol. XXVII.

[2] Excerpt from 'Ore Deposits of Northern Black Hills,' J. D. Irving, *Bull.* 225, U. S. Geol. Surv., p. 131. See also 'Geology of Homestake Lode,' S. F. Emmons, professional paper No. 26, U. S. Geol. Surv., 1904.

duction of pyrite that followed rhyolite intrusions. The greater part of the auriferous gravel was derived from the Homestake lode.

Gold also occurs as thin continuous films between the fracture planes of schist fragments and as fine specks between the layers of the schist directly underlying the conglomerates. This gold has been deposited from chemical solution as noted above.

In Deadwood and Blacktail gulches, which cut into the gold-bearing formation, as well as into the country rock, recent alluvial gold gravels were formerly worked which contained the metal in the form of a twice redeposited product.

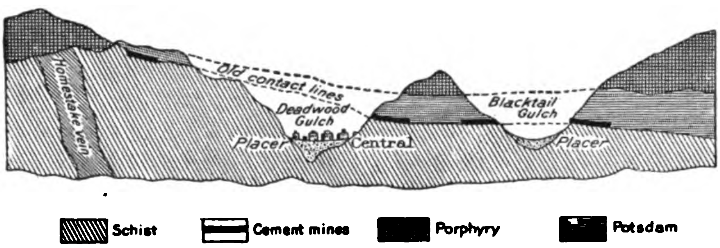


Fig. 249.—Approximate geological sketch from Homestake eastward. (Devereux.)

According to J. D. Irving,[1] gold is also found in the higher Cambrian strata—as at Spearfish Creek—although not in workable amount.

As shown in Fig. 237, the Cambrian formation of the Black Hills contains intercalated gold deposits which were formed by subsequent mineralization of calcareous rocks.

2. *Gold-bearing Detrital Deposits of Carboniferous Formations.*

In Australia auriferous detrital deposits occurring in the Carboniferous have been known for a long time. Thus, R. Daintree[2] described the occurrence of gold in water-worn particles in a conglomerate of the Carboniferous (glossopteris stage) near Peak Downs in Queensland. It is also known[3] that the lowest strata of the Carboniferous rocks which cover broad areas in the region north of Gulgong, in New South Wales, sometimes carry gold in paying amount. The gold-bearing conglomerates discovered by Clarke at Tallawang, in Phillips county of the same colony, are of identical age. In Tasmania gold was found in the coal measures of Hobart.

[1] J. D. Irving: 'A Contribution to the Geology of the Northern Black Hills,' *Annals* New York Ac. of Sc., Vol. XII, No. 9, p. 296. Also, 'Geology of the Northern Black Hills, South Dakota,' *Bull.* 225, U. S. Geol. Surv., p. 131. Also, 'Economic Geology of the Northern Black Hills,' Prof. paper No. 34, U. S. Geol. Survey, 1904.

[2] R. Daintree: 'Occurrence of Gold in Australia,' *Quart. Journ.* Geol. Soc., 1878, Vol. XXXIV, p. 435.

[3] Phillips-Louis: 'Ore Deposits,' 1896, p. 649.

In America we may mention the case of Corbett's Mills in Colchester county, Nova Scotia, described by Dawson and F. Harth,[1] where rounded gold grains are found in a Carboniferous conglomerate, which, it is to be noted, is traversed by gold quartz stringers. European deposits of this kind have been known for some time. Gold has been extracted from the lower Carboniferous conglomerates of Bessèges in southern France (department of Gard), according to Phillips[2].

3. *Gold Deposits of the Mesozoic Formations.*

The gold-bearing conglomerates of the Mariposa formation (Marine Jurassic), in Placer county of the Sierra Nevada region of California, are of special interest. According to Lindgren,[3] they contain finely divided gold, with some pyrite, but no magnetite nor ilmenite. As the Mariposa strata are traversed by some of the largest gold quartz veins of the Sierra Nevada, these conglomerates, if their gold was not really formed by later impregnation, indicate an older and now destroyed group of primary gold deposits in California.

Other gold-bearing Mesozoic conglomerates are known in the northern part of California on Klamath river and in Siskiyou county. These were regarded by Dunn as old river gravels, but according to Diller[4] they contain marine fossils. The gold is accompanied by red hematite and pyrite.

Mesozoic gold-bearing sediments are also found in Australia and in New Zealand. In the Otago, Nelson and Southland districts of that colony such sediments are found in the Jura, and at Mt. Buster in the Cretaceous.[5]

Tertiary gold deposits having the character of true placer gravels will be mentioned under the latter title.

III. Lead- and Copper-bearing Permo-Triassic Gravel Deposits.

The Copper and Lead Deposits of Cap Garonne, near Toulon.

According to B. Lotti,[6] quartz conglomerates of the Permo-Triassic series enclose an ore-bearing zone 0.5 to 1.2 m. thick at Cap Garonne. The pebbles composing the conglomerates consist of vein quartz in a cement

[1] G. Becker: Cited in *Zeit. f. Prak. Geol.*, 1898, p. 217.

[2] G. Becker: *Zeit. f. Prak. Geol.*, 1898, p. 216.

[3] W. Lindgren: 'An Auriferous Conglomerate of Jurassic Age from the Sierra Nevada,' *Am. Journ. Sci.*, 3d series, 1894, Vol. XLVIII, p. 275.

[4] Cited in *Zeit. f. Prak. Geol.*, 1898, p. 216

[5] H. A. Gordon: 'Hysteromorphous Auriferous Deposits of the Tertiary and Cretaceous Period in New Zealand,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, p. 292.

[6] B. Lotti: 'Sul giacimento sedimentario cuproplumbifero di Cap Garonne,' Rassegna Min., Vol. XIV, No. 16, 1901. Also *Zeit. f. Prak. Geol.*, 1901, pp. 281–283.

of kaolin or mica. In the upper portion of the bed granules and crystals of galena with barite are interspersed, while in the lower part black oxide of copper (melaconite) occurs mixed with copper glance and remnants of still undecomposed copper pyrite. From the occurrence of copper glance in the interior of large quartz pebbles and of fragments of copper pyrite in the cement, B. Lotti infers that we have here a genuine detrital deposit. The ores are believed to be derived from Cambrian and Archean rocks underlying the Permian. These older rocks do actually contain many quartz lenses and veins with galena, zinc-blende, copper pyrite and bournonite which are worked at Bormettes, Verger, Rieille, Cogolin and elsewhere.

B. RECENT PLACER GRAVEL DEPOSITS.

General Characters.

Placer gravels are deposits of loose, more or less rolled, material derived from the destruction of older deposits, lying on the earth's surface, or at least very close to it, and containing paying amounts of ore or precious stones. Gem gravels are not treated in this work. As the ore in the gravel is usually seen even by an inexperienced observer, and since the metallic particles can generally be easily extracted by simple washing, the gravels have almost always been the first objects of mining in the history of a country. For this very reason they were usually the first of all the deposits of a country to be exhausted. Thus, for example, practically nothing remains of the old gravel-mining industry of Germany and Austria, though it was formerly quite important. In newly discovered or recently explored countries, however, placer mining often develops into vast proportions as the first phase of mining. Hence in selecting examples of gravel deposits for description we are, practically, limited to such regions.

According to the nature of the paying metal or ore in the gravels, we may speak of gold gravels, platinum gravels, tin gravels, etc., but the expression iron-ore gravels is but little used.

As the material composing placer gravels has been exposed to all the influences of the atmospheric air and of the water seeping through the upper strata of the soil, placers will be found to contain, in the main, only relatively insoluble, and in general refractory metallic compounds which, moreover, are protected by their great specific gravity against easy removal by water. The insoluble native metals, such as gold, platinum and others, and oxidic ores (tin-stone, magnetite and others) are naturally most common. Easily oxidizable metals and metallic sulphides will not, as a rule, be found in gravels. In the destruction of older deposits, minute and scantily interspersed metallic compounds may be preserved, provided they possess the necessary insolubility and weight, and thus we find that metals which are otherwise most scantily distributed, such as platinum, which in its original site would hardly anywhere pay extraction, are concentrated within the gravels in paying amounts[1].

These placer gravels are usually grouped into two classes, according to their position with reference to the deposit from which they are derived, and in part, also, according to the manner of the original process in which they are derived from the primary ore deposit:

1. *Residual gravels, i. e.,* of local origin (eluvial gravels).

2. *Alluvial gravels, i. e.,* formed by washing. These may again be subdivided according to age into Recent, Pleistocene and Tertiary gravels.

Residual gravels, the rarer of the two groups and certainly the less extensive, are found in the immediate vicinity of the original ore deposits, and quite independent of water courses, viz., on mountain slopes, plateaus and sometimes even on mountain summits. As they consist of the residual products left in the weathering of the original ore-bearing material, they contain almost no foreign matter, and they are distinguished by a great uniformity of material as compared to the gravels transported and assorted by water. The rounding of their constituents is but very slight; the larger fragments are found to be but slightly abraded along the edges, and there has hardly been any sorting of the material according to size. This detrital gravel is the work of air and rain, the same agents whose activity is so marked in the formation of gossans; in fact, gossan and residual detrital gravels often pass one into the other. Changes of temperature also have a share in the disintegration of original deposits, and the wind contributes to the sorting of the fragments, according to size. In arid regions and under a tropical sky, the extreme difference of temperature between the day with its burning solar heat, and the quickly ensuing night with its tremendous radiation, cause an extensive crackling and disintegration of the outcrop of the primary deposit. Even hard masses are splintered. The wind starts up the débris thus formed, sweeps away the finer particles, and leaves the larger fragments and the heavier of the smaller pieces behind. Showers of rain wash the heavy ingredients a few meters downward, in case the ground has a little slope, or spread them out in all directions on level ground. Thus, in the case of local or residual gravels, there has often been both a chemical and a mechanical redeposition of the original metalliferous material in place, but no transportation of it to any great distance.

On the contrary, the gravels formed by the transporting and washing ac-

[1] B. v. Cotta: 'Erzlagerstätten I,' Freiberg, 1859, p. 100. C Zerrenner: 'Anleitung zum Gold,- Platin- und Diamantenwaschen aus Seifengebirge,' etc., 1851.

tion of water are found only in the channels of brooks and rivers, in fresh water lakes or along the sea-coast. They lie for the most part within the present valleys or along the present shore, but are also often found in stretches of fluviatile sediments, sometimes intersecting the present direction of the valley on old river terraces, or in sheets covering plateaus (California, Ohlapian in Transylvania) and finally in old shore terraces above the present level of the sea. Their material is always much rolled, and for the most part is assorted, according to the size of the ingredients, into shingle, gravel, sand, clay, mud, etc. The same is true also in part of the ore content therein.

In the placer gravels the ore is ordinarily distributed in a peculiar way, as may be seen from the diagrammatic longitudinal section of a placer deposit of this kind found in the Ural (Fig. 250). The particles of

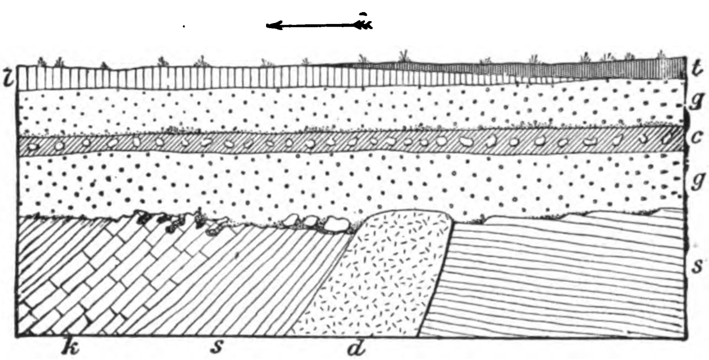


Fig. 250.—Ideal section of a gold placer deposit.
s, slate; k, limestone; d, diabase; g, gravel; s, sand; c, conglomerate; l, loam; t, turf.

the heavy metal are concentrated to a remarkable degree upon the bedrock or along the surface on which the alluvial masses were laid down. The higher strata are ordinarily very poor, and are not sluiced, being thrown on the dump. The larger nuggets, found as rarities, almost always occur at the base of the gravel beds. The character of the bedrock and the condition of its surface materially influence the richness of the gravel layer directly above it. Rocks such as limestone and dolomite, which are corroded and abraded by running water in such manner as to assume a roughly pitted or gouged surface, catch the heavy metallic particles in the depressions, while those rocks which are polished smooth by water, such as many fine-grained gneisses, eruptive rocks, diabase and others, are unable by their outcrop to stop the heavy grains of metal rolling over them. Those rock strata are the best collectors which are steeply inclined and dip in the direction of the former river course; horizontal or backward dipping beds are much less effective. Many schistose rocks, which show exfoliation in their outcrops in the river bed, catch the finest particles of heavy metals between the loosened folia, so that the uppermost part of the outcropping schists may sometimes be worked for gold or platinum, as in the Ural. If large boulders occur in the lower layers of the gravels, rich pockets are often found between them.

Sometimes the bedrock on which the gravels rest shows narrow grooves or troughs of considerable length which are apt to be particularly rich (see Fig. 255), or the surface may contain pot-holes (pockets) with an exceedingly rich yield. Down stream below such rich pockets, if the overlying soil is small in amount and there has been a partial natural removal, this wealth is wont to be expanded fanlike in steadily diminishing amount. Hence the practical prospector, rendered alert by such expansions, is often able to recognize the direction in which a rich pocket is situated.

Where a gravel deposit contains an impervious layer intercalated in it, such as a sand or gravel with firm ferruginous cement (false bedrock), the heavy metals are often concentrated on the surface of this layer, so that the deposit may have two or more workable layers. This is also true in cases in which lava streams flowing into and spreading in valleys have temporarily interrupted the deposition of gravel, sand or clay, a phenomenon repeatedly encountered in western North America and in Australia.

As such intercalated layers of solid material were often regarded as the real bedrock, the error being perceived only later, they were called "false bedrock" (*loshnyi plotik* in the Ural).

In some cases gold-bearing layers occur at several higher levels. Thus K. Schmeisser[1] says that the section seen in the shaft of the Ross United Gold Mine, at Hokitika on the south island of New Zealand, shows no fewer than eight layers, carrying a considerable gold content, though not in any case workable.

It would, however, be an error to assume that in a cross section of a river valley the lowest layers of shingle, gravel or sand are throughout the richest. On the contrary, the values in this horizon are variable and pay gravel is ordinarily limited to streaks of greater or less width, which are found in one place in the center of the valley, in another along one side, now nearer, now further away, from the present water course. Several such rich streaks may even run side by side through the alluvial valley lands, but only in its lower course, where the fall of the stream is slight.

The presence of the gold in the lowest layers of stream gravels was for-

[1] K. Schmeisser: *Australasien*, p. 90.

merly regarded as due entirely to a natural process of concentration by gravity during deposition. This process is indeed possible in some cases, but in many other cases, as correctly pointed out by F. Posepny[1], this assumption alone will not suffice. The material of the gravel is in many cases not "classified and sorted," but forms an alternation of layers showing great diversity in size of grains and pebbles. Where the coarsest and heaviest material lies lowest, as is so frequently the case, while higher up the material becomes lighter and lighter, we must remember that these layers were deposited one after the other, perhaps at long intervals. It is only in narrow gorges that all the material covering the bottom land was carried down into the valley and deposited by a single flood.

The accumulation of the finer metallic particles at the bottom of loose alluvial masses is much more satisfactorily explained by the assumption of a subsequent downward migration of these particles, as was also pointed out by F. Posepny. Every assayer is familiar with the fact that slight shocks to a cup containing a powdered sample of ore suffice to make the heavier metallic granules slip down through the lighter barren particles and become concentrated at the bottom. Even in undisturbed masses of considerable size, like the piles of crushed ore at the Pribram works, this action may be observed, according to F. Posepny. If the heaps are examined after being untouched for some time, the galena particles are found to be concentrated at the bottom. In porous deposits of gravel and sand, which are traversed by vigorous ground-water currents, as is usually the case in gravels, and in which, therefore, the smallest particles are subject to the thrust of the water, such a gradual sinking of the finest particles of heavy ores may readily be possible. In fact, archæologists have long been familiar with the phenomena of the sinking of coins and the like in loose soil, and Helmhacker very properly explains the rare occurrence of metallic lead in the lower layer of placer gravels of the Ural to be due to the gradual downward movement of particles of shot from the guns of hunters who have discharged their weapons in this vicinity.

The interesting question whether the concentration of certain ores occurring in gravels (native gold, tinstone) is also possible in a chemical way by means of chemical solution and subsequent precipitation will be discussed for the various classes of gravels in subsequent pages.

From what has been said, it is evident that certain alluvial gravels may, after certain intervals, acquire new wealth. Such examples are well known in the flood plains of many large rivers of Australia; for example, Buller River, and in the Otago district of New Zealand. According to K. Schmeis-

[1] F. Posepny: 'Genesis,' p. 207.

ser,[1] the Clutha River in the Otago gold field supplies new and rich material to the gravels at every melting of the snow.

In some regions the gold-bearing gravel brought down by the river finally reaches the ocean, as seen on the east coast of Australia between the Clarence and Richmond rivers, and along the coast of Oregon in the United States, and at Vladivostok in southeastern Siberia. The sea itself by the alternation of tides and the play of breakers liberates the heavy metallic particles from the rocks of the coast. On the coast near Naples, for example, the sea has formed deposits of magnetite-augite sand out of the detritus of the lavas of Vesuvius. On the coast of the Baltic (for example, at Warnemünde), the ore particles of the Pleistocene strata outcropping on the shore are locally enriched; the northern drift marl especially, with its multitude of fragments of crystalline rocks, contains such ore grains. According to Deecke, the water in its concentration of such sands, which may eventually contain in local areas as much as 64% of iron ore, is aided by the wind, which at ebb tide blows away the light grains of quartz and silicates.

If a stream whose gravels contain metallic grains be followed down from its source to the sea, the size of the heavy metallic particles in the gravels may often be seen to diminish more and more. Large rivers, as a rule, are able to carry out to the sea only the finest particles; only short, vigorous mountain torrents along steep or precipitous coasts are able to carry the heavier grains into the sea.

Conversely, in many cases, on proceeding up stream through a placer-bearing river valley, a place will finally be reached where large fragments of ore will be found with part of the gangue still adhering, and where the fragments of ore are but little rounded by rolling and may even still exhibit crystalline forms. Finally the prospector may discover on the slope of the main valley or on the side of the valley the deposit which supplied the river, which may be a workable vein or stock. Often, however, the ore in the alluvial sands of the upper river course suddenly stops without any genuine deposit being found, despite the most active search. This simply means that the upper limit has been reached of those rocks which contain sparsely distributed ore, perhaps only in minute particles, which have been concentrated in the river gravels. Thus, in the Ural, the platinum of the alluvium comes to an end as soon as the upper limit of the olivine rock or of serpentine has been reached in the river valley. Concerning the nature of the primary deposit which is to be looked for, the attentive observer will sometimes find useful indications from the presence of characteristic associated minerals in the placer gravels. Thus, in the Ural, long before actual

[1] K. Schmeisser: Australasien,' p. 100.

proof had been obtained that the platinum came from olivine rocks, this origin was surmised from the fact that chromite was found accompanying it, and eventually particles were found which showed platinum intergrown with chromite. In some cases even the less valuable or worthless companion minerals may draw attention to the ore in the gravels themselves, as, for example, the blackish magnetite and ilmenite sand which so often indicates gold. In searching for gold-bearing marine gravels especially, such blackish sand may put the prospector on the right track.

Youthful as the placer gravels are, geologically considered, yet in many cases they have already suffered dislocation. Numerous examples are known from California of faults traversing both gravel beds and the country rock, and often materially affecting the mining operations. Figure 251 represents such a case, which shows plainly that the fissure was only formed after the deposition of the gravel. Sometimes basalt dikes have arisen along such displacement fissures, as in several cases in Plumas and Sierra counties of California. Slightly folded gravel beds have also been observed in that country.

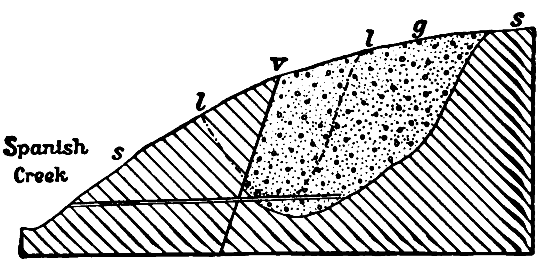


Fig. 251.—Cross-section of a faulted gold placer gravel deposit, Spanish Creek, Cal. s, slate; g, auriferous gravel; v, fault; l, boundary of old channel.

The following detailed descriptions of typical examples illustrate the several varieties of gravel deposits grouped according to the kind of ore obtained from them:

Placer Gravel Deposits of Various Kinds.

(A) Magnetic Iron Ore Gravels.

Near the mouth of the St. Lawrence river the north bank shows vast deposits of titaniferous magnetite sands derived from the norites outcropping in the upper basin of the stream. The best known deposits are those of Moisie bay, near the mouth of Moisie river. Others are found in the vicinity of Mingan, Bersimis, Natasquan, Kagashka and Batiscan.

The magnetite sands occur in layers several centimeters thick in the ordinary river sand. An especially rich sample from Moisie contained 70.10% of ore carrying 55.33% Fe and 16% Ti O_2.[1]

Similar sands are also found on the shore of Lake Champlain.

Gold-bearing magnetite sands are also known on the west coast of North America between Cape Mendocino in California and the mouth of the Umpqua river in Oregon.[2]

Titaniferous magnetite sands are found for a distance of 13 miles along the southwestern coast of the north island of New Zealand,[3] near the town of New Plymouth, and were proved by dredging to extend outward for a distance of three miles from the land. The source of this deposit must be the volcanic area around Mt. Egmont. Smelting experiments were made with these sands, which were briquetted with clay. The sands contained 52.88% Fe_2O_3, 29.60% Fe O and 8.14% Ti O_2.

Similar sands found on the west coast of the south island are gold-bearing and were washed for that metal.

Titaniferous magnetite sands are also known from the shore near Yamakushinai, province of Iburi, and near Kobui, province of Oshima, on the Japanese island of Yesso.[4]

In Europe titaniferous magnetite sands were found on various coasts with volcanic rocks, as, for example, at some points in the Bay of Naples, but nowhere in payable deposits.

An occurrence known to Agricola, but of no importance as a source of ore, though geologically interesting, is found in the Seifengründel (Seufzergründel) near Hinterhermsdorf in Saxon Switzerland.[5]

At that place a tiny brooklet flows into the Kirnitzsch river from the west, and, despite its present small volume, has formed extensive deposits of stony clays and sands along its little valley. At the Hohwiese these alluviums, probably of late Pleistocene age, are underlain by thin layers of black sand, and this material is also found between the boulders of the lower course of the brook. The sands are not only exceedingly rich in magnetite, but they also contain quartz, hornblende, augite, bronzite, yel-

[1] J. F. Kemp: 'A Brief Review of the Titaniferous Magnetites,' School of Mines. *Quarterly*, 1899, Vol. XXI, pp. 331–333.

[2] Phillips-Louis: 'Ore Deposits,' 1896, p. 26.

[3] E. Metcalf Smith: 'On the Treatment of New Zealand Magnetic Iron Sands,' *Journ*. of the British Iron and Steel Inst., 1896, I, p. 65.

[4] J. F. Kemp: 'A Brief Review of the Titaniferous Magnetites,' School of Mines *Quarterly*, 1899, Vol. XXI, p. 65.

[5] A. W. Stelzner: 'Ueber das Vorkommen von Edelsteinen in der sächs. Schweiz,' *Sitzungsber*. d. Isis., Dresden, 1870. O. Herrmann and R. Beck: 'Erläut. zur geol. Spezialk. von Sachsen.' Sect. Hinterhermsdorf-Daubitz. H. Oehmichen: 'Die böhmischen Granatlagerstätten und die Edelsteinseife des Seufzergründels bei Hinterhermsdorf,' *Zeit. f. Prak. Geol.*, 1900, pp. 13–17.

lowish hyacinth, dark spinel (ceylonite) and more rarely green diopside, apatite, and finally, in more isolated instances, ruby. The source of the iron ore and its companion minerals (other than quartz) was a small stock of olivine and hornblende-bearing glassy basalt, situated a little above the Hohwiese. The basalt holds magnetite, bronzite, spinel and augite, and, in its brecciated contact zone with the Turonian sandstone cut by it, contains inclusions of a gabbro carrying medium grained bronzite and very rich in spinel.

(B) Lateritic Decomposition Products Rich in Iron Ore.

The laterites of Brazil, a geologically recent formation not older than the Pleistocene epoch, are rich in fragments of iron ore, described under the name of *tapanhoancanga,* after the sierra of the same name.[1] They are found in the province of Minas Geraes at the towns of Itabira, Villarica and Marianna, where they form a sheet 3 to 13 ft. thick, covering the outcrops of hematite schists and other crystalline rocks. The deposit consists of fragments and pebbles of micaceous hematite schist, hematite, magnetite and limonite, together with those of various crystalline rocks, especially quartzite and itacalumite. The cement, which is often scanty, is hematite. This deposit contains gold, diamonds, topaz, rutile, zircon and other rarer minerals.

A peculiar deposit of this class (laterite) is found in Surinam. According to G. C. DuBois,[2] the ferruginous laterite has a cellular slag-like surface and holds nodules and globular concretions, varying from the size of fine shot up to particles two centimeters across. These concretions have a scaly but not radial structure. They consist chiefly of limonite (86.9% F_2O_3), but also contain newly formed quartz, chalcedony and remains of silicates. Besides this concretionary limonite the laterite of Surinam also contains oolitic bauxite.

(C) Tinstone Gravels.

1. *The Tinstone Gravels of the Erzgebirge and the Neighboring Mountains.*

In view of the great number of primary tin deposits in the Erzgebirge of Germany it is not surprising that tin-bearing gravels are widely distrib-

[1] v. Eschwege: 'Beiträge zur Gebirgskunde Brasiliens,' 1832, p. 141. Pluto Brasiliensis, 1838, p. 225.

[2] G. C. DuBois: 'Beitr. z. K. der surinamischen Laterit- und Schutzrindenbildungen,' Tschermak's *Min. Mitth.*, 1903, Vol. XXII, p. 31.

uted in that region. These alluvial deposits were worked as early as the 12th century and as recently as the 19th century.[1]

Most of the tin-bearing gravels of the region occur in the granite areas or the adjacent contact zones. The deposits are of two kinds: (1) Residual formations, consisting of unassorted angular rock débris, that has moved but little down hill and may be found to extend far up the slopes, as in the region of the Greifenstein, near Geyer, and at numerous points near Eibenstock and Johanngeorgenstadt; (2) water-worn débris filling recent valley bottoms of Pleistocene and in one case Tertiary age. The recent and Pleistocene occurrences cannot be sharply discriminated in every case; the Tertiary occurrences will be specially described at the end of this chapter.

The valley gravels form more or less perfectly stratified beds of pebbles or sand, usually covered with sandy clays or peat, and composed mainly of rolled fragments of granite, and a variety of contact-metamorphic slates, especially andalusite-mica-rock and tourmaline schist, as well as vein quartz and vein breccias. The tinstone occurs mainly in minute granules, but also in larger grains, which sometimes still exhibit a crystalline form; in rare cases it was found in larger lumps, which, however, are always coalesced with quartz and represent fragments of greisen rich in cassiterite. Greisen débris, associated with fragments of tourmaline schist, is the best indication of the presence of tinstone in such gravels, a fact well known to the old placer miners of the Erzgebirge. Besides cassiterite, topaz, apatite, beryl, fluorspar and malachite were also found, and at various points free gold. Gold from the gravels of the region of Annaberg is mentioned in a decree by the Prince Elector of 1657, and was also known in the placers of Eibenstock and Johanngeorgenstadt.

The Tertiary gravels of the Erzgebirge are confined to the region of the Steinhöhe at Seifen, near Abertham,[2] where they occur under conditions quite analogous to those of the Tertiary gold gravels of California and the tinstone gravels of Australia, namely, in a remnant of an old river valley, protected from denudation by lava sheets. On the granite and the phyllite bedrock adjoining the granite, and altered by it through contact metamorphism as shown in Fig. 252, there rests a fluviatile deposit, about 10 m. (32.8 ft.) thick, which petrographically resembles the formations of the lower Oligocene. The basal and most widely distributed gravel bed

[1] H. Schurtz: 'Der Seifenbergbau im Erzgebirge und die Walensagen,' Stuttgart, 1890.

[2] G. Laube: 'Geologie des Böhmischen Erzgebirges I, Prague,' 1876, pp. 195, 197. A. Sauer: 'Erläut. zu Section Wiesenthal,' 1884, p. 81. F. Schalch: 'Erläut. zu Section Johanngeorgenstadt,' 1885, pp. 119–123. Lohrmann: 'Einiges aus der geolog. Vergangenheit des Erzgebirges,' Annaberger Berichte, 1898.

is from 10 to 20 ft. thick and consists of pebbles of granite, for the most part resembling greisen, of fine-grained granite, vein quartz breccia, tourmaline schist, andalusite-mica-rock, quartzite schist and phyllite quartz nodules. This material alternates with sands which are rich in black tourmaline granules and mica. Above this follows a red clay, 1 to 4 ft.; then a sandy yellowish or bluish clay, 1 to 2 ft., and finally quartz sand with cross bedding, 2 to 5 ft. thick.

The gravel series is covered by basalt, developed partly as nepheline and partly as leucite basalt, underlain towards the northwest by a thin phonolite sheet. The lower layers of this deposit contained so much cassiterite that it was extracted by underground (drift) mining and washed, the industry building up the town of Seifen. As the rocks south of the place are traversed by numerous tin veins recently worked at the Sanct

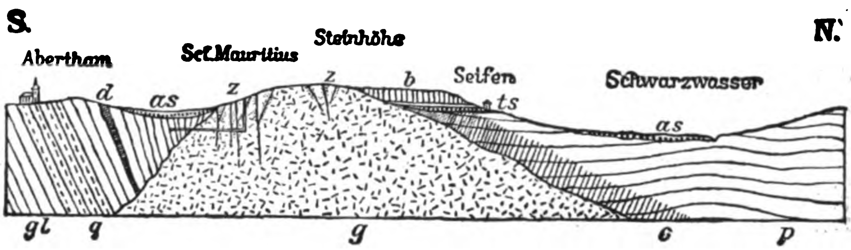


Fig. 252.—Ideal section through the tin district of Abertham in the Erzgebirge.
gl, mica schist; q, quartz schist; p, phyllite; c, contact-metamorphic schists; g, granite; z, tin veins with Zwitterzones; ts, Tertiary tin placers; b, basalt; d, diorite; as, alluvial and diluvial tin gravels in part with cover of bog.

Mauritius mine, the presence of tin in these Tertiary formations may be readily explained.

2. *The Tinstone Gravels of Cornwall.*

The tin-bearing gravels of Cornwall were formerly the most important alluvial deposits of Europe. The facts concerning this district have been summarized by Phillips and Louis,[1] from whose account the following notes are derived:

The following varieties of tin-bearing gravels (called "stream-works") are distinguished in Cornwall:

1. In gravels now forming in existing streams and on sea-beaches, in which the tin ore usually occurs in angular or sub-angular grains (valley gravels).

[1] Phillips-Louis: 'Ore Deposits,' 1896, pp. 28–33.

2. Tin gravels of valley terraces, old and elevated river deposits, occurring at various heights up to 700 ft. (210 m.) above the present water courses. Still older terraces at St. Agnes Beacon contain pebbles and grains of tin ore.
3. Tin-bearing angular débris at and below the outcrop of tin veins (residual tin-ore gravels).

One of the most interesting sections of Cornish tin gravels is that of the Happy Union stream works in St. Austell valley, near Pentewan harbor. In this valley just above St. Austell a number of small streams, which come from the granitic Hensbarrow mountains, unite and receive the tributaries from the tin region around Polgooth mine. The bedrock of the valley consists of slate rock.

According to J. W. Colenso, the section of the Happy Union stream works is as follows, from above downward:

9. River sand, silt, etc.	20 ft.
8. Sea sand with oak trunks and bones of *Megaceros hibernicus* (giant elk) and *Bos primigenius*	20 ft.
7. Silt with few stones and bone remains	2 ft.
6. Sea sand with fragments of marine shells	4 in.
5. Silt with Cardium edule.	10 ft.
4. Layers of leaves, acorns, moss, etc	6 to 12 in.
3. Layers of peat	6 to 12 in.
2. Tin ground where the whole of the ores occurs associated with débris of granite and tourmaline slate and in lumps up to 10 pounds in weight with some gold	3 to 10 ft.
1. Bedrock consisting of clay slate (killas) whose surface lies 18 m. (59 ft.) below the present high-water level.	

This part of the Cornish coast, therefore, has subsided since the deposition of the tin ore gravels. Farther up the valley the marine strata are lacking in the section of the tin gravels.

The tinstone of the Cornish gravels either forms more or less rounded grains and crystals, or it occurs in the form of wood tin, and in somewhat rare cases as pseudomorphs after organic remains. Particular importance attaches to the occurrence in the tin gravels of the Penetwan and Carnon valleys of fragments of stags' antlers that are partly impregnated with tinstone, iron oxide and som[illegible]

A specimen from the [illegible] ling to J. H. Collins:

CaP_2O_5	[illegible]
$CaCO_3$	[illegible]
CaF_2	0.50 "
FeS_2	1.65 "
Fe_2O_3	0.62 "
SnO_2	2.60 "
SiO_2	0.22 "
Org[illegible]	12.1[illegible] "
	100.[illegible]

While there can be no doubt that by far the greater part of the tin ore has been brought together by the mechanical action of water, yet a small part represents segregations from solutions of tin oxide, which were formed probably within the gravels, or were conveyed to the valley bottoms with the ground-water current. Such re-deposited tinstone may be especially represented by the wood tin of the Cornish gravels.

The tin gravels of Cornwall were exploited as early as Roman and Greek times,[1] when Great Britain was called "Cassiterides" (tin islands). At present the true gravels of that country have long been exhausted and abandoned. What is called "stream working" at the present day is merely the extraction of the tinstone contained in the tailing of the stamp-mills of the valleys. In 1894 6% of the total tin production of Cornwall came from the washing of these lean slimes.

Tinstone gravels were formerly worked in Brittany and western Spain.

3. *The Tin-bearing Gravels of Australia.*

On the continent of Australia the most important tin gravels lie in New South Wales, near the Queensland boundary, in the New England district. They were discovered in 1853 by W. B. Clarke, but were not worked until 1872, though in the colony of Victoria tin gravels were washed some years earlier. The tin gravels of the New England district lie partly on the floor of the valleys of the present day and partly in portions of Tertiary valleys, which were left unattacked by denudation, being mostly protected by basaltic lava streams. The gravel tin is derived from granite masses which are permeated by numerous tin veins. Among the most important gravel areas of this region may be mentioned Bendemere, Watson's Creek, Stanthorpe, Copes Creek, near Inverell, and especially Vegetable Creek. Fig. 253 gives a picture of the conditions of bedding of the so-called "deep leads" of the locality last named. It shows the lateral flank of an old Tertiary valley bottom with its lava cover, which is here composed of several flows somewhat different petrographically. The gravels of this kind in Rose Valley near Vegetable Creek, discovered in 1880, yielded in 9 months 553.5 tons of tin. Besides these old gravels, the alluvial ones are exploited. According to H. Louis,[2] the tin works of Vegetable Creek produced:

	1886.	1895.
Mines ...	169 tons.	286 tons.
Allu ...	761 "	499 "
Ol ...	962 "	115 "
	1,892 tons.	900 tons.

[1] ..., bei Griechen und Römern IV,' p. 81 *et seq.*

[2] ... 'Geology of the Vegetable Creek Tin-Mining Field,' ...7, p. 23. Referred to by Phillips-Louis, 'Ore Deposits,'

4. *The Residual Tin Deposit of Mount Bischoff.*

The greatest example of residual tin gravels known is found on Mount Bischoff in northwestern Tasmania.[1]

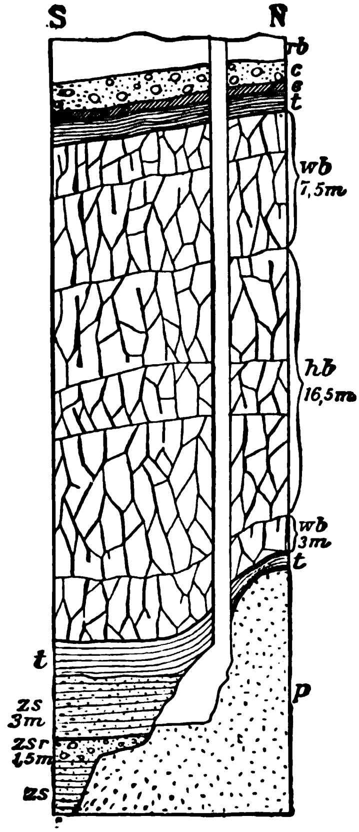


Fig. 253.—Vertical section of the old shaft of the Wesley Bros., Vegetable Creek. (Phillips-Louis.)

rb, red earth; c, conglomerate; e, ironstone; t, clay; wb, white basalt; hb, hard basalt; zs, stanniferous sand; zsr, pay streak; p, porphyry.

This mountain consists of Paleozoic clay slates and quartzites, with lesser amounts of sandstone and dolomite. The slate rock is traversed by numerous dikes of a quartz porphyry, which may be derived from the

[1] A. v. Groddeck: 'Zur Kenntniss der Zinnerzlagerstätten des Mt. Bischoff in Tasmanien.' *Zeit.* d. D. G. G., Vol. XXXVI, p. 642 *et seq.* W. Ferd. Kayser: 'On Mt. Bischoff,' Australas. Asso. for the Advanc. of Sc., Hobart, Tasmania, Sec. C., 1892. W. v. Fircks: 'Die Zinnerzlagerstätten des Mt. Bischoff in Tasmanien,' *Zeit.* d. D. G. G., 1899, Vol. LI, p. 431 *et seq.*

same eruptive hearth as a granite outcropping west of Mount Bischoff, at a distance of 3.5 km. (2 miles) in the form of a "massif." Altogether 17 large dikes of this kind are known at the mountain, showing great variety of trend, and forming the horseshoe-shaped crest of the summit. Towards the north and west tin veins and barren quartz veins appear, while at the foot of the mountain, at the northeast and south, a Tertiary basalt sheet with underlying clay conceals the bedrock proper.

The quartz porphyries, and in part also the slates traversed by them, have for a distance of ¾ km. (½ mile) from the mountain top undergone a very profound alteration, as shown first by A. von Groddeck and subsequently demonstrated in detail by Freiherr W. von Fircks. All the original feldspar and mica, and in the extreme stage of alteration even the primary quartz, have been replaced by topaz, tourmaline, secondary quartz and tinstone, to a less extent also by fluorspar, arsenopyrite, pyrite and magnetic pyrite, with some siderite. The proportion of each constituent in this mixture of these newly immigrated minerals varies. Those rocks richest in tourmaline are apt to be the poorest in tinstone. On the other hand, the selvages of the larger veins are said to consist sometimes of nothing but topaz (var. pycnite) and tinstone.

The true tin lodes, such as the North Valley lode and the Mount Bischoff lodes, contain quartz, iron spar, arsenopyrite, pyrite, tinstone, fluorspar, pyrophyllite and wolframite; only in rare cases do they also carry topaz. Their selvages are rich in sericite.

Neither the tin-bearing quartz porphyries, nor the true veins of the tin ore formation, are as important as the mass of residual débris produced from the veins by weathering. These residual deposits occasionally prove to be astonishingly rich, and are known as Faces.

White Face lies on the south slope of the mountain on both sides of an altered quartz porphyry dike. This deposit, like some parts of the two others, consists of angular or subangular fragments of the cassiterite-bearing topazized quartz porphyry, with associated topaz-quartz sand, rich in tinstone. The Slaughter-yard Face, further up the mountain, besides the materials just mentioned, also contains slate, together with much pyrite and the products of its decomposition, monazite and bismuth, all doubtless derived from a tin vein.

These talus gravels extend up to the mountain summit, often lying at an angle of 45°, and sometimes attaining a thickness of 21 m. (69 feet) and more. An older gravel deposit, with somewhat rolled material, has been found at the foot of the mountain.

The richest deposit, called Brown Face, lies on the east slope of the mountain, in the horseshoe-shaped basin enclosed by a ridge made by dikes of porphyry. The deposit consists of tourmalinized slate and topazized quartz porphyry, with much limonite and iron ocher. It covers many acres and is in places 295 feet thick. The tin ore forms a fine crystalline sand readily washed out in some parts of the deposit, while in rare cases the ore occurred in the form of slabs of 10 or even 20 tons in weight, lying vein-like in the mass. The material has evidently resulted from the disintegration of a network of fissures and stringers of tin rock traversing and impregnating the slates and the quartz porphyries.

The Mount Bischoff tin deposits were discovered in 1871, as stream tin in Forth river. In 1873 the deposits of residual débris were first worked. The Mount Bischoff Tin Mining Company, operating on the three residual deposits just described, yielded an unusually large production. From its foundation to the close of 1902 it produced 60,946 tons of tin ore, with a content of 70% of tin in round numbers.

5. *The Tin-bearing Gravels of Banka and Billiton, Malay Archipelago.*

The Dutch East Indian Islands of Banka and Billiton contain one of the most important alluvial tin deposits of the globe.[1] Banka lies off the southeast coast of Sumatra, while Billiton lies somewhat farther east between Sumatra and Borneo. Both islands are mountainous. According to R. Verbeek they, together with the small islands in the intervening Gaspar strait, consist of steeply upturned beds of sandstone and slate, with numerous granite stocks. The age of the sediments is probably pre-Carboniferous. These rocks are altered near the granite by contact metamorphism, forming hornstones cut by numerous offshoots and dikes of granite.

The primary tin-vein and greisen deposits of these islands have already been mentioned (p. 213). The stanniferous gravel resulting from their destruction is of two kinds: (1) Residual gravels, "kulit gravels," or mountain tin gravels; (2) alluvial gravels, "kollong" or valley gravels. The former occur in the upper parts of the valleys and on the slopes near the outcrops of the lodes. The material has not been transported far, and in places contains huge lumps of cassiterite, larger than any found in the veins now worked, some of the lumps weighing over 1,000 kilograms.

A good idea of the occurrence of the stanniferous valley gravels is afforded by the accompanying longitudinal section through a deposit, after van Diest (Fig. 254). The cross-section shows: At the bottom, directly above the bedrock (called "kong") consisting of granite, hornstone, sandstone or schist, lies the "kaksa," a sand containing abundant granules of

[1] R. Verbeek: 'Geologische Beschrijving von Bangka en Billiton,' *Jaarboek* van het Mijnwezen in Nederlandsch Oost-Indie, 1897. Th. Posewitz: 'Die Zinninseln,' *Jahrb.* d. kgl. ungar. geol. Anstalt, Vol. VIII, 1886.

tinstone, the sand holding 2-4%, rarely up to 10% of tin. Besides cassiterite, it contains much quartz and lesser amounts of limonite, tourmaline, monazite, bauxite and curious obsidian balls and cones, which strikingly resemble the moldavites of Moravia.[1] Above the "kaksa" sand comes a cover 4-16 m. (13-53 ft.) thick of sand and clay. Nearer the point where the river empties into the sea the alluvial material is of course finer, clay and slime predominating, and the tin ore in the "kaksa" of such localities is very fine (tin ore flour). Some of the gravels also carry gold. The overlying gravels contain too small an amount of tin ore to pay for working.

Tin has been worked in Banka since 1710, mainly by Chinese companies, but lately under the supervision of European engineers. In 1896 Banka

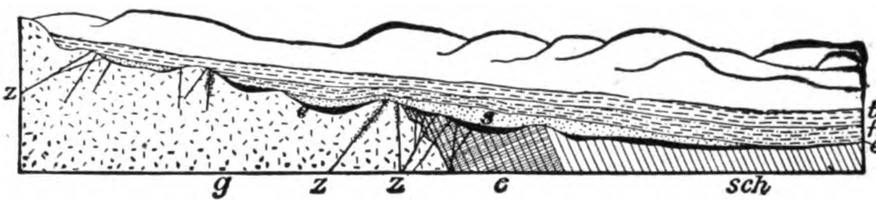


Fig. 254.—Ideal cross-section of a valley tin placer, a "Kollong" placer of Banka. (Van Diest.)

g, granite; sch, slate and quartzite; c, contact-metamorphic slate; z, tin veins; e, rich tin beds (kong) on bedrock; s, coarse sand; fs, fine sand in part earthy; ts, clay sand.

produced 148,122 pikuls, that is, in round numbers, 9,184 tons of tin, and Billiton about the same amount.

6. *The Tin-bearing Gravels of the Malay Peninsula and of Other Parts of Asia.*

There is an exceedingly close resemblance between the stanniferous gravels of Banka and Billiton and those of the Malay Peninsula, but the latter have a far greater production, furnishing over half of the world's supply of tin. The long mountain range extending along the southwest coast of the country contains a great number of stocks of granite intruded in shales and sandstones. Associated with the granites, or at any rate in their vicinity, there are tin veins and impregnation zones. The older rocks are in many cases uncomformably overlain by a granular limestone.

In almost all the numerous valleys descending from the mountain crest and draining granitic terranes, tin gravels are found, to wit:

[1] F. E. Suess: 'Die Herkunft der Moldavite und verwandter Gläser,' *Jahrb.* d. k. k. geol. Reichsanst., Vienna, 1900, Vol. L. With full bibliography.

On the west coast, especially in the States of Perak, Selangor and Sungei Ujong.

In the interior, in the States of Jelebu and Negri Sambilan.

On the east coast in the State of Pahang.

The most important deposits are in Perak and Selangor.

According to H. Louis, in the Malay Peninsula the lowest or pay gravel bed is 4-5 feet (1.2-1.5 m.) thick and covered by barren gravel to an average thickness of 15-20 ft. (4.5-6 m.), or rarely 80 ft. (24 m.). In an exceptional case observed at Sorakai Kinta, in Perak, over 80 feet of pay sand occurred under 20 feet of overburden. The average richness of the workable tin sands is about 1%, though it is exceptionally as much as 20% (Saiak Kinta, in Perak) in black tin.

A remarkable form of residual tin gravels is found, according to H. Louis,[1] at various points on both flanks of the Malayan mountain range, especially at Bukit Ebu, near Kernai, and at Dreda and Goa Tumbus, in Jalor. These are tinstone-bearing quartz sands, cemented by limonite looking like silicious bog iron ores. The cement seems to be derived from the decomposition of the iron pyrite and arsenopyrite of neighboring tin veins. The material which overlies decomposed granite is so hard it has to be crushed in order to wash the tinstone out of it. The amount of tin varies from 1% black tin, the lowest amount payable, to as much as 30%. A curious deposit at Goa Tumbus contains, besides tinstone, various oxidized lead ores, viz., anglesite, cerussite, pyromorphite and mimetesite, as a result of the weathering of both tin greisen and galena.

The rich tin deposits of the Malay Peninsula and the neighboring archipelago were known long before the Christian era. Perak, in particular, has produced tin for a long time, and as early as 1677 tin coins existed in Perak and Queda. The British colonies Singapore, Malacca and Penang, the so-called Straits Settlements, though producing no tin themselves, are the main ports of exportation for it. In 1897 the Malay States produced 45,632 tons of metallic tin.

In 1900 the total exportation of tin from Perak was 21,166 tons, and from Selangor 16,041 tons.

Tin gravels similar to those of the Malay Peninsula occur in the adjoining Siamese States, especially in Kedah and in certain parts of Burma.

7. *Tin-bearing Gravels of Mexico.*[2]

Among the alluvial tin deposits of Mexico, those of Tepezala in the State

[1] 'Ore Deposits,' 1896, pp. 597–603.

[2] José G. Aguilera: 'Geographical and Geological Distribution of the Mineral Deposits of Mexico,' *Trans.* Am. Inst. Min. Eng., Vol. XXII, 1902, p. 506.

of Aguas Calientes seem to be of special interest. Judging from the material in the Freiberg collection, the tinstone occurs in kidney-shaped masses formed of concentric shells and hence of concretionary origin. The nodules, which vary up to the size of a nut, are in part covered with a crust of hematite foils. Besides these concretions, which seemed to have been formed *in situ,* there are also found obtuse-angled, apparently rolled, fragments of a tinstone showing a centric structure.

8. *Tin-bearing Gravels of South Africa.*

In South Africa tin gravels are known in the Embabaan district in Swazieland, which are genetically connected with the tinstone-bearing pegmatite veins briefly described on page 217, and are worked in the "Ryan Tin Works." The tinstone is found in the alluvium of the valleys, which is 0.9-4.5 m. (2.9-14.7 ft.) thick, containing corundum, monazite, æschynite and magnetite,[1] associated with the tinstone.

(D) The Gold Gravels.

Gold Placers of the Southern United States.

The placer gravels of Georgia, Alabama and the Carolinas have long been worked. They are dredged in valley bottoms, whose gravels are fluviatile. At Dahlonega and elsewhere the outcrops of the gold veins and the residual gravels on the slopes near by are washed by hydraulic methods.

The Gold-bearing Gravels of California.

The auriferous gravels of California occur in a belt about 700 miles long that lies upon the lower western slopes of the Sierra Nevada. The

[1] A. T. Molengraaf· *Ann. Rep.* State Geol. of South African Republic, 1897.

[2] Important papers: Laur: 'Gisement et exploitation de l'or en Californie,' *Ann. d. Mines*, 1863, 6, III, p. 347. H. Credner: 'Beschreibung von Mineralvorkommen in N.-America,' *Berg u. Hütten. Zeit.*, 1866, p. 209. J. A. Phillips: 'On the Chemical Geology of the Gold Fields of California,' *Phil. Magaz.*, 1868, Vol. XXVI, p. 231. J. D. Whitney: 'The Auriferous Gravels of the Sierra Nevada of California,' Cambridge (Harvard College *Mem.*), 1879–1880. J. Leconte: 'The Old River Beds of California,' *Amer. Journ. Sc.*, 1880, iii., XIX, p. 176. Ross E. Browne: 'The Ancient River Beds of the Forest Hill Divide,' 10th *Ann. Rep.* Cal. State Mineralogist, 1890, pp. 437–440. H. W. Turner: 'Auriferous Gravels of the Sierra Nevada,' Amer. Geol., 1885, p. 372. A. C. Lawson: 'The Post-Pliocene Diastrophism of the Coast of Southern California,' *Bull.* Dep. of Geol. Univ. of Calif., 1893, Vol. I, p. 115. W. Lindgren: 'Two Neocene Rivers of California,' *Bull.* Geol. Soc. of Am., 1893, Vol. IV., p. 257. 'Geological Atlas of the U. S. Geol. Survey,' Sacramento and Placerville *Folios*, 1894. W. Lindgren and F. H. Knowlton: 'Age of the Auriferous Gravels of the Sierra Nevada,' *Journ.* Geol., 1896, Vol. IV, p. 881. J. F. Kemp: 'Ore Deposits,' 1900, pp. 353–362.

general geologic structure of this range and its primary gold deposits have already been described.

Three different kinds of auriferous gravel deposits may be distinguished in California. The grouping, being based on the mode of working, brings together formations not quite of the same geologic age.

(a) Alluvial and Pleistocene gravels on the floor of recent river valleys.

(b) Bench gravels found on the valley terraces of the middle part of the stream valleys, not very far up above the present channel; the deposits are mostly worked by the hydraulic methods.

(c) Gravels of Eocene to Pliocene age on plateaus and high valley terraces, mainly exploited by underground work ("deep gravel" mines).

(a) Alluvial and Pleistocene Auriferous Gravels.

The alluvial and Pleistocene gravels (shallow placers) of California generally consist of rather coarse, rolled material, especially of the harder drift of the older gravels, here occupying its third place of deposition. The gold was sometimes found in such gravels in rather coarse nuggets, but occurred mostly in fine grains and minute flakes. In contrast with the older Tertiary gravels, the gold is very irregularly distributed and is accompanied by magnetite, less commonly by zircon, garnet and occasionally a little platinum and osmiridum. These placer deposits are confined to the bottoms of the present valleys and are mainly of fluviatile, but in part of littoral origin. They have been worked since 1849, and though very rich, were practically exhausted by 1860. This early work was done by very primitive methods, the ground being often gone over several times.

(b) The Late Tertiary Auriferous Gravels (Bench Gravels).

These deposits are distinguished from the preceding group solely by their higher elevation above the present streams. They form terraces midway up the valley slope, their elevation above the streams making it possible to work them by hydraulic methods. By this work great quantities of gravel and sand have been washed down the valleys, ruining large tracts of fertile bottom land. This is now regulated by a national débris law.

These two classes of gold-bearing gravels are also found in other parts of the United States, as, for example, according to Kemp, at Santa Fé in New Mexico, in California gulch, near Leadville, at Fairplay and in San Miguel county, Colorado, in the Sweetwater district in Wyoming, at Pioneer, Last Chance and Prickly Pear gulches at Helena, Montana, in the

Black Hills of Dakota, on Snake river and elsewhere in southern Idaho, and at several points in Washington and Oregon.

(c) The Tertiary Gold Gravels.

The Tertiary auriferous gravel deposits are remnants of old river courses, preserved from destruction and denudation, usually by lava streams. They grade into littoral terrace deposits and were formed in various epochs of the Tertiary period. The detailed mapping of these deposits by the United States Geological Survey gives a record from which it is easy to show the course of these ancient valleys, some of which run parallel to the present valleys, while others cross them at right angles. These formations extend along the slopes of the Sierra in a zone 250 miles long and reaching an elevation of 2,100 m. (7,000 feet) above the sea. Their thickness is often very great, as, for example, at Mount Columbia, where it is 180 m. (590

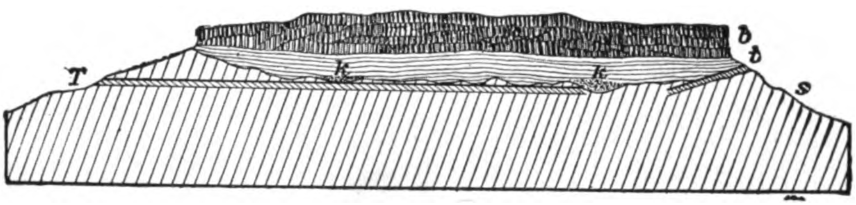


Fig. 255.—Section through Table mountain, California. (Whitney.)
s, older schists; k, channels, that is to say, gravel-filled grooves on the schist; t, pipe clay and sand; b, basalt; t, tunnels (Buckeye tunnel).

ft.), but generally it is very much less. They cover areas 45-300 m. (150-1,000 ft.) broad. The bedrock on which they rest ordinarily shows distinctly the form of a trough, with one or more deeper channels, as shown in the section, Fig. 255. The flanks of these old valleys in the rock floor are called "rims," the floor itself is called the "bedrock." In the tilted schists, the channels as a rule cling to the softer strata.

The material deposited in these ancient river beds consists of shingle, gravel, sand, clay (pipe clay), volcanic tuff and solid lava sheets of basaltic, rhyolitic or andesitic composition. The drift of the coarser layers consists principally of quartz, in part of metamorphic schists and in certain late Tertiary occurrences also of volcanic rocks. The drift is frequently cemented by a siliceous matrix. The very common occurrence of silicified wood proves the circulation of siliceous waters. Bones and teeth of extinct Tertiary vertebrates have been found in the gravels, while the clays contain leaf impressions of late Tertiary species. The auriferous gravels contain vertebrate remains, together with human remains and stone bowls and implements of prehistoric man, at Table mountain in Tuolumne county, California.

The volcanic tuffs occasionally found intercalated between the fluviatile strata are conceived to be streams of mud that flowed down into the old valleys after great eruptions of ashes in the mountains.

These old river courses have in many cases been affected by subsequent dislocations. Not only has the entire mountain region risen as compared with the coastal region since the formation of these auriferous gravels, as shown by LeConte and others, but the gravel deposits themselves are traversed by fissures and displaced. Such a case is illustrated by Fig. 251. Sometimes eruptive dikes are intruded along fault planes in the gravels. It is said that crumpling of the fluviatile strata has also been observed.

The richest gravels lie next to the bedrock, the gold being usually concentrated in the old channels cut in the solid bedrock. The auriferous pyrite found in these basal ("blue") gravels will be discussed further on.

Recent detailed mapping and study of the Tertiary gravels shows that they may be divided, according to their age, into the following stages:

From the Eocene a few doubtful occurrences are known. The greatest number belong to the Miocene, while the gravels which contain andesite tuffs and lavas are referred to the Pliocene. In Amador and Calaveras counties these fluviatile Pliocene strata pass into marine gravels. These represent deposits in the great gulf which in Pliocene time filled the central valley of California. These marine gravels occur from 500 to 700 feet above the sea level.

The exact age of the beds lying immediately below the basalt sheets, from which the prehistoric remains have been obtained, is as yet doubtful, but they probably belong to the Pleistocene.

2. *The Gold Placers of the Yukon and Other Districts in Alaska.*

The discovery of the rich gold placers in the Yukon district, especially on the Klondike, a tributary of the Yukon, has directed widespread attention to this remote region.

The Yukon, the largest river of Alaska, is formed by the union of its several forks, in Canadian territory, at about 60° north latitude; it main-

[1] Important papers: G. M. Dawson: 'Report on the Yukon District in 1887,' Geol. Surv. of Canada, 1887–88, Vol. III, part B. J. E. Spurr: 'Geology of the Yukon Gold District, Alaska.' 18th *Ann. Rep.* U. S. Geol. Survey, 1898, part III. S. F. Emmons: 'Map of Alaska with descriptive text containing sketches of the Geography, Geology and Gold Deposits,' U. S. Geol. Survey, 1898. O. Nordenskjöld: 'En Expedition till Klondike och Yukonterritoriet,' Ymer, 1899, part 1. J. B. Tyrrell: 'Glacial Phenomena in the Canadian Yukon District,' *Bull.* Geol. Soc. Amer., 1899, Vol. X, p. 193. F. Andersson: 'Das Klondike-Goldfeld,' etc. Essener *Glückauf*, 1901, No. 6, 7.

tains a northwesterly course up to the Arctic circle; then turns southwest and empties into Norton Sound, a part of Behring Sea. The richest placers are in Canadian territory in an area 21 km. (12.6 miles) broad and 43 km. (25.8 miles) long, lying between the Klondike and Indian rivers, both entering the upper Yukon from the east.

Farther down stream on United States territory the rich placers of the Forty Mile district and of Birch Creek occur in the valleys of these lateral branches of the Yukon.

In these regions the country rock is formed of crystalline schists, partly mica schists, hornblende schists, crystalline limestones and diabase tuffs, but principally of Paleozoic slates and quartzite schists. All these schists are intruded by granites, and the most of them are cut by pyritic gold quartz veins and some of them by veins of pegmatite.

The gold-bearing gravels rest as a rule directly on a schist bedrock, while occasionally a clay stratum forms the "false bedrock." Usually the schist bedrock is much decomposed and holds gold caught in its cracks and fissures. The workable gravel is usually confined to a layer 0.6 m. (1.9 ft.) thick, which exceptionally reaches a thickness of 3 m. (10 ft.) above bedrock. The cover of overlying barren gravel is usually 2.5-3 m. (8-10 ft.), but may amount to as high as 7.5 m. (24.5 ft.) in thickness. The gravels consist of large and generally flat slate fragments and slightly rolled quartz pebbles, mingled with sand. The gold occurs in part as rather coarse particles, occasionally still showing vein quartz. The accompanying heavy minerals are galena, magnetite, brown hematite, hornblende and garnet.

In the Klondike area, between the Klondike and Indian rivers, which has become the most famous, the prevailing bedrock is a mica schist, whose quartz stringers were in some cases found to be gold-bearing. The gold-bearing deposits are divided into valley gravels, lower terrace gravels and upper terrace gravels. The last named consists of a brown, non-auriferous upper layer and a whitish, quartz-bearing, auriferous lower layer. This layer, known there as "white gravel channel," is the oldest gravel formation of the region. It consists of the proportion of 75-80% of quartz and mica schist pebbles, imbedded in quartz sand and containing mica scales.

The Eldorado deposits are the best known of the valley gravels. The lowest 39 claims of this tract contained extraordinary amounts of coarse gold. This gold was of very low fineness (only 750). The flake gold of the lower Bonanza valley, on the contrary, carries less silver.

Among the upper terrace gravels those of Gold Hill at the union of the two valleys just named furnished the most gold. The gold there increases in amount from the edge of the terrace inward. The "white gravel channel" is there up to 25 m. (81 ft.) thick, and holds scales and rounded nuggets of gold. On the contrary, on the upper terrace of French hill, at the junction of French Valley with Eldorado Valley, sharp-edged or angular nuggets are found, often studded with crystals.

As the gravel beds of these Arctic districts are for the most part in a frozen condition from one end of the year to the other, they have first to be thawed out in development work, and the gold-washing proper is limited to the brief summer season.

The first gold find of the Yukon river region was made in 1871 far from the Klondike, on Dease lake, near the source of Stikine river, in British Columbia, where placer mining was actively continued until 1887. Subsequently the gravels on Birch creek and in the Forty Mile district were dis-

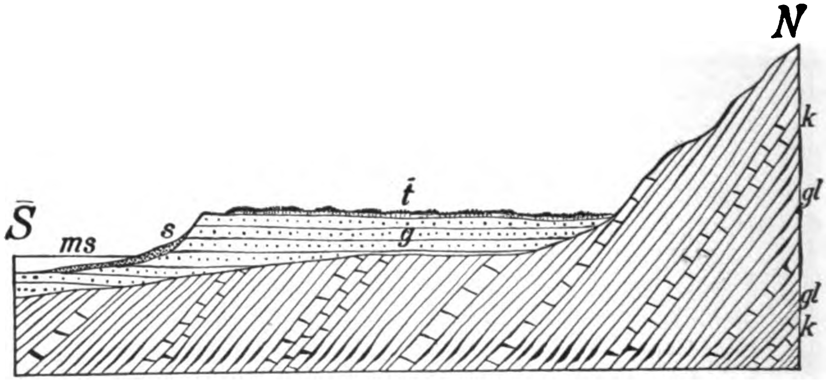


Fig. 256.—Cross-section of the beach placers and bedrock at Cape Nome, Alaska. (Schrader and Brooks.)

gl, mica schist and gneiss; k, limestone; t, turf and soil of the tundra; g, old gravel, sand and clay; s, gold-bearing sand and gravel; ms, sea-level.

covered, and it was not until the autumn of 1896 that those of the Klondike region proper were found. The value of the gold production of the Yukon district in 1900 was about $18,000,000. The total value of the available placer gold stored there by nature was estimated by McConnell at $95,000,000.

3. *The Gold Gravels of the Cape Nome District.*[1]

In recent years the gold deposits of Cape Nome in Norton Sound, Alaska Territory, discovered in the autumn of 1898 and worked since the summer of 1899, have aroused considerable discussion. They are located in 64.4° north latitude, in a very bleak, inhospitable region on the shore of

[1] Weber: 'Die Goldlagerstätten des Cape Nome Gebictes,' *Zeit. f. Prak. Geol.*, 1900, pp. 133–136.

Behring Sea and in the valleys of Snake and Nome rivers, which debouch there. On the seashore they consist of a stratum of reddish, gold-bearing sand, up to 10 cm. (4 inches) thick, thinly covered with gravel, and extending along the shore for a great distance, with an average breadth of 22 m. (72 ft.), while in the valleys the gold-bearing sands lie under the mossy peat which covers the tundra, the sand being separated from the bedrock by a clayey layer poor in gold. The valley gravels contain much garnet and magnetite, with here and there some platinum and cinnabar.

We give a characteristic cross-section of the beach gravels in Fig. 256, after Schrader and Brooks.[1] In the summer of 1899 three men washed from the beach sand about $470 worth of gold per man from Aug. 19 to 25. The new town of Nome City quickly sprang up, and by the end of the summer of 1899 as many as 5,000 gold-seekers had flocked there.

Gold gravels have also been discovered on the east coast of Siberia, opposite Cape Nome.

4. *Gold Gravel Areas in South America.*

The most interesting districts of gold-bearing gravels in South America are those of Surinam (Dutch Guiana), British Guiana and Venezuela.

With the exception of a narrow coastal zone of younger sediments, the country rock of forest-covered Surinam[2] consists of a complex of massive and schistose crystalline rocks, especially granites, gneisses, mica schists, amphibolites and quartzites, in which gabbros, diabases and diorites are intercalated. Several of the northward-flowing rivers, particularly the Surinam, show deposits of gold-bearing gravels. According to G. DuBois most of this gold is derived from gold-bearing diabase masses, only a tenth of the placers receiving their precious metal from eroded gold lodes, as, for example, the de Jong placer and the Guyana Goud placer. Most of the placers could receive it only from gold-bearing diabases. This derivation is indicated by the close association between placer gravels and diabases. Moreover, in many instances the ordinary residual product of the weathering of these rocks has been profitably washed for gold. The higher gravels on the slopes of the diabase mountains contain less gold than those lower down.

The concentration of the gold in the laterite is illustrated by Du Bois by the following data: At the Victoria placer, slightly decomposed dia-

[1] 'Preliminary Report on the Cape Nome Gold Region, Alaska,' U. S. Geol. Survey, Washington, 1900.

[2] G. C. Du Bois: 'Geol. bergm. Skizzen aus Surinam,' Freiberg, 1901. Also 'Beitr. zur K. der Surinamischen Laterit und Schutzrindenbildungen, Tschermak's *Min., u. petro. Mitth.*, 1903, Vol. XXII, p. 39. W. C. H. Staring: 'Jetsover de Geol. Gisteldheit van Suriname.' Alg. Konst en Letter-Bode, 1884. K. Martin: 'Bericht über eine Reise nach Niederl. West Indien,' Leiden, 1888.

base showed 0.2-0.6 grams per ton, while the decomposed rock *in situ* showed 3 to 10 grams per ton. The greatest enrichment in this sharp residual laterite gravel is found a little above the contact of the laterite débris with the deep laterite underlying it as a bedrock.

The placer gold is usually in grains, often as fine as dust. Quite rarely large nuggets are found, like that found in 1896 on de Freitas placer, weighing 5.876 kilograms. In the Victoria placer and elsewhere the so-called black gold is found, that is to say, lumps with a shining black crust of ferrous oxide.

The discovery of the gold placers occurred in 1874. The annual gold production of all Surinam reached its maximum in 1891, with 1,236.919 kilograms. In 1899 it was 872.249 kilograms.

The most important gold placer deposit of British Guiana is that of Omai, on the left bank of the Essequibo river, 120 miles from Georgetown. According to E. E. Lungwitz,[1] the gold varies from particles as fine as dust up to nuggets weighing 1,057 grams and it is always accompanied by considerable auriferous quartz. According to the same author the gold is partly derived from a huge vein of feebly auriferous aplite, a fine-grained dike-granite, in which it is associated with cupriferous iron pyrite, while another part is derived from disintegrated conglomerates and sandstones. The manner in which Lungwitz imagines the transportation of this placer gold to have taken place is discussed later.

In Venezuela the gold placers on the Yuruari river in the highlands of Upata, south of the Orinoco, discovered in 1849, led to the subsequent opening of the famous primary deposit near Callao (see page 300).

The placer or derivative, as well as the primary gold deposits of French Guiana, are treated in detail by E. D. Levat.[2]

According to this author the gold deposits of that region are principally found at the contact between gneiss or crystalline schists and intrusions of igneous rocks, more especially where masses of diorite and diabase are found in the schist. These rocks predominate, for example, in the bed-rock of the placers of St. Elie, Dieu Merci, Elisée, Pas-trop-tôt and Awa. In most cases gold has also been found in several neighboring valleys, radiating from a diorite or diabase mass of this kind.

These rocks possess a primary gold and silver content, the gold being either free (as proven even in perfectly fresh, undecomposed samples) or

[1] E. E. Lungwitz: 'Ueber die regionalen Veränderungen der Goldlagerstätten, Diss. Rostock.' Leipzig, 1899. Same author: 'Die Goldseifen von Britisch-Guiana,' *Zeit. f. Prak. Geol.*, 1900, pp. 213–218. J. B. Harrison and H. J. Perkins: '*Rep.* on the North Western Distr. of Brit. Guiana,' Georgetown, 1897–98.

[2] E. D. Levat: 'The Gold Fields of French Guiana,' 'The Mineral Industry,' New York, 1899, Vol. VII. Also 'Guide Pratique pour la Recherche, etc., de l'Or en Guyane Française,' Paris, 1898.

contained in the pyrite, which sometimes constitutes as much as 5% of the rock. The following table, after Levat, shows amount of gold in unaltered igneous rocks of French Guiana:

	FeS_2 %	Gold Grams per 1,000 kg.	Silver Grams per 1,000 kg.
Diorite from Roche creek	5.2	2.0	6.0
Diorite from Pichevin creek	4.1	1.5	2.0
Diorite from Maripa with visible free gold	0.5	24.0	4.0
Amphibolite ("Grison") from Telegraph Mountain in Cayenne	1.4	0.24	0.02

Compare this with what has been said on page 16 on the primary native gold found in diabases and diorites.

These "greenstones" are the source of the gold found in certain cemented residual gravels called "roches à ravets" (cockroach rock, so called because of the porous and cavernous nature of the rock). These rocks are lateritic limonites, resembling bog iron ore and being a product of weathering. They do not form horizontal strata in the valleys, but spread over both hill and valley as a universal mantle.

The following analyses by Levat confirm this theory of the origin of this concretionary ironstone from diorites or diabases:

	Fe_2O_3	Al_2O_3	SiO_2	CaO	P_2O_5	MgO	H_2O
1. Sample I from Maripa	54.70	12.10	8.55	5.50	0.67	6.10	7.80
2. Sample II from Maripa	59.40	14.80	9.50	6.80	0.02	5.40	9.10
3. Sample from Roche creek at Awa	60.35	14.10	7.40	....	....	....	14.10
4. Sample from Pichevin creek at Awa	59.40	14.50	6.50	4.80	1.02	3.10	10.10
5. Sample from Central Settlement at Awa	58.25	13.15	8.10	....	....	....	....

These gossan rocks contain free gold, always alloyed with silver, as is the case with the primary gold in the diorite and diabase. The amount varies from 0 to 18.5 grams per ton and in exceptional cases as much as 73 grams of gold per ton, with 16 and 20 grams of silver per ton, the fineness of the gold being only 700-850 thousandths.

Besides these residual deposits, true river placers are also known in which the barren gravel is mainly quartz, the deposits resting on a bed-rock decomposed into clay. Immediately above this clay is their richest layer, having a thickness of 5-10 cm. (2-4 inches). Such placers occur, for example, on the Appronague, Sinnamary and Mana rivers. The gold may be derived from quartz veins carrying pyrite and some arsenopyrite, bedded veins which traverse the crystalline schists at several points and give rise to cataracts where they cross the river valleys Some of these veins, like that of Adieu Vat, proved to be workable.

In Chili the gold placers at Punta Arenas and in northern Tierra del Fuego were reported on by R. Pöhlmann.[1] Their parent rock is stated by him to be a mica schist carrying lenses of gold-bearing quartz. The material has been transported by glaciers and spread out by rivers.

5. *The Gold Placers in the Ural.*

The middle and southern sections of the Ural mountains, especially in the vicinity of Bogoslovsk, Nizhne Tagilsk, Berezovsk, Miask and Orenburg are rich in gold placers[2], whose geologic relations are described by A. Karpinsky in an official report made after a detailed survey.

The gold placers of the Ural form stratified deposits 1½ to 3 ft. in thickness, seldom as much as 13.12 ft. They extend usually a distance of 20-40 m. (65-131 ft.), but sometimes to 200-500 m. (656-1640 ft.). Only in very exceptional cases are placers found 4.5-12 km. (2.7-7 miles) long, as in the gravels of Peschanka in the Bogoslovsk district. Their breadth is sometimes slight, 2-4 m. (6.5-13 ft.), usually about 20-40 m. (65-131 ft.) exceptionally even 100 m. (328 ft.) and more. Sometimes the gold-bearing sediments lie directly under the sod, but they are commonly found under a cover of barren gravel, sand and clay, 0.5-4 m. (1.6-3 ft.) or even 20 m. (65 ft.) thick. The cover is called "turfa," because, in the case of the first gravels worked, peat (German *torf*) actually covered the gravels, and since then this German word has been used for every kind of cover. The gold-bearing sands and gravels almost always rest directly on bedrock ("plotik"); only in rare cases are they separated from it by layers of barren gravel or sand.

Most of the placers lie on the east slope of the Ural mountains, in the broad valley flats of the middle course of the present rivers and usually below the present level of the rivers. As shown by the remains of *Elephas primigenius, Rhinoceros tichorhinus* and other Pleistocene animals found in the gold-bearing strata, the deposits belong to the Pleistocene, and represent a period of active valley-filling, which gave rise to the many lakes

[1] R. Pöhlmann: 'Die Goldseifen bei Punta Arenas und im nördl. Feuerland,' *Vehr. d. Deutsch. wissensch. Ver. in Santiago* (Chile), Vol. IV, pp. 307–318.

[2] A. Karpinsky: 'Sur les sables aurifères' (in Russian), 1840. R. Helmhacker: 'Der Goldbergbau der Umgebung von Berezovsk,' *Berg u. Hütten Zeit.*, 1892, p. 45. F. Posepny: 'Die Golddistricte von Berezov und Mias am Ural,' *Archiv f. prakt. Geol. zu Freiberg*, 1895, Vol. II, pp. 499–598.

and swamps of this part of the mountains, some of which are also filled with gold-bearing detritus. Thus, for example, gold-bearing sediments are known in Lake Ilmen.

The gold occurs as minute granules or scales, nuggets being rarely seen. The largest nugget known weighed about 36 kilograms (80 lb.) and came from the Tsarevo-Alexandrovsky placer of the Miask district. The distribution of the gold often varies. However, the rules given on page 619 generally apply. The amount of gold in the Ural gravels usually varies between 0.57 and 2.6 grams per ton. Below 0.57 grams, washing no longer pays. However, where sufficient water is present, and the conditions are otherwise favorable, this lower limit is closely approached, as for example at Bogoslovsk, where a placer deposit 2 m. thick, with an average content of no more than 0.6 grams of gold per ton, has been exploited, though it lies under a barren cover 2.5 m. (8.2 ft.) thick. In exceptional cases pockets of much richer sands were encountered in the placers, some with a content of 16 kilograms of gold per ton.

The gold is accompanied in all the placers by magnetite, more rarely by hematite, menaccanite, chromite, platinum, cinnabar, garnet, zircon, cyanite and diamond.

Most of the gravels lie on the crystalline schists, and some of the schists act on the floor of the placer deposits as gold riffles.

The primary gold deposits of the Ural, from which the gravels are derived as a disintegration product, are described on pages 303, 304 and 310.

While the gold veins of the Ural are said to have been discovered as early as 1745, placer gold did not attract attention until 1814, when it was mined at Berezovsk. It seems, however, that the prehistoric Chudes washed gold in these mountains, for in the Chude tombs, according to Posepny, gold bracelets were found having composition identical with the placer gold of the locality.

In 1899, the Ural produced 10,448 kilograms of gold, to wit, Perm government 6,015.34 kg., Orenburg 4,420.7 kg., Ufa 12.3 kilograms.

6. *The Gold Placers of Siberia.*[1]

Both West and East Siberia are rich in gold placers. In West Siberia, within the Tomsk mining district, placers are found in the barren steppe extending east of the Ural around Tobolsk-Akmolinsk and in the Altai region in the district around Semipalatinsk-Semiryechinsk. They are generally poor. In the regions adjoining the Chinese boundary, placer

[1] M. W. Gribassowy: 'Der Goldbergbau in Sibirien,' Berlin, 1896. E. Levat: 'L'or en Sibérie orientale,' Vol. II, Paris, 1898. René de Batz: 'The Auriferous Deposits of Siberia with Mining Map of Siberia,' *Trans.* Am. Inst. Min. Eng., 1899, Vol. XXVIII, p. 452.

deposits are worked which hold but 0.16-0.21 grams and rarely with but 0.32-0.40 grams of gold per ton of sand. At some points the abundance of water and the great thickness of gold-bearing strata, rising as high as 10 m. (32.8 ft.), make it profitable to work gravels containing but 0.108 grams per ton of sand. In the Altai region, sandstones and clay slates together with metamorphic granitic and dioritic masses form the bed-rock. Farther north, too, in the forest area of the Tomsk mining district, in the Marrinsk, Biisk, and Kuznetsk, active placer mining is carried on. Gold veins have also been opened at Dimitrievsk, Voshresensk, Proroko-Ilinsk, etc.

In Central Siberia the very rich placers of the Yenisee basin are now mostly exhausted; others occur in the mining districts of Yenisee North and Yenisee South, as well as Krasnoyarsk and Kainsk. The gold-bearing gravels varied between 1.4 and 2.8 m. (4.6-9 ft.) in thickness and in exceptional cases reached as much as 2.8 m. (9 ft.). The pay gravel is covered by 0.7-10.65 m. (2-35 ft.) of barren material. In 1882, lode mining was begun here.

The placers of East Siberia occur in the Irkutsk mining district, where they are distributed over a vast area. On the whole they are richer than those of West Siberia. The following are the main regions: The Lena Basin, the Nerchinsk district in Transbaikalia, on the head-waters of the Amur, Shilka and Argun, and the Amur basin proper, together with the coast region south of the mouth of that stream.

The auriferous alluvial deposits of the Lena region lie on the north-west slope of the Yablonoi mountains, especially along the Olekma and Vitim rivers and their tributaries. About Olekma the placers average 2.7-4.3 grams and in the vicinity of Vitim 7.8-12.8 grams, rising in exceptional cases to 14.3 grams per ton. The gold is rather coarse grained, but occurs only rarely in nuggets. Occasionally two or even three gold-bearing layers occur one above the other. Like the Klondike region, the entire bed of workable material is perpetually frozen.

In Transbaikalia, the principal placer deposits are in the Chita, Aksha and Nerchinsk regions and at Bargusinsk and Upper Udinsk in the western part of that country.

The gold gravels of the Amur region form four groups on the left tributaries of the river: (1) Between Amur and Seya, above Blagovyeshchensk; (2) on the tributaries of the Gilyui and the Bryanta; (3) on the Selenga; (4) on the upper course of Imana river. Gold veins are also worked there.

In the coast area, the richest placers are found in the river valley of the Amguna, which empties into the Amur. Besides the fluviatile placers of these districts, the auriferous marine sands of Askold island near Vladivostok are worked in some places by dredges, which excavate and treat sand of the sea-bottom.

Gold mining in Siberia did not begin until the 19th century. In 1831, gold mining was begun in the Altai, in 1832 in the vicinity of Nerchinsk, in 1836 on the Briyussa in the Yenisee area, in 1849 on the Lena, in 1866 in the coast region, in 1868 in the Amur basin proper.

According to M. W. Gribassovy, West Siberia produced in 1893 2,915.64 kg.; East Siberia, 29,827.98 kg. of gold; all Russia in the same year, 44,733.78 kilograms.

7. *Gold Placers in India.*

A second Asiatic country containing gold placers is India, including the Himalayan States. According to Phillips-Louis' summary[1], the placer districts of nearer India all lie in zones of metamorphic schist, whereas in Ladak the alluvial gold comes from quartz lodes traversing Carboniferous strata; in Candahar its primary source is in Cretaceous rocks; and finally along the Himalaya, from Afghanistan to the frontiers of Assam and Burma, as well as in the Salt Range, the alluvial gold is derived from Tertiary sediments, into which it was carried from eroded metamorphic schists.

Among the more important occurrences may be mentioned those of Wynaad, a mountain land between the coast of Malabar and the Nilgherry highlands in southern India. At this place the alluvial gold is derived from pyritous quartz veins, traversing granite-gneiss and various crystalline schists. The veins themselves have also been mined.

Important gold placers formerly existed in the province of Mysore, but they, too, now seem to be abandoned. Vein mining still flourishes, however, especially in the Kolar goldfield east of Bangalore, where pyritous gold quartz veins are found in gneiss and hornblende gneiss.

Gold is also washed in the southern part of the province of Chota Nagpur, where *rhizoda* are found in the crystalline schist formation called "Darutar series."

Gold has also been obtained from the Irawaddy and some of its tributaries in British Burma.

8. *Gold Placers of Australia.*

Gold placers are known to exist in practically all the Australian colonies. Some of them have yielded and are still yielding a large output.

[1] J. A. Phillips and H. Louis: 'A Treatise on Ore Deposits,' London, 1896, pp. 560–576.

Victoria, besides its alluvial placers, possesses others of Miocene, Pliocene and Pleistocene age, some of them buried under basalt sheets, like those of California[1]. Of all these the most important are thin alluvial placer deposits of Ballarat, Beechworth, Sandhurst, Maryborough, Castlemain, Ararat and Gippsland which yielded enormous amounts in the early days after their discovery and afforded many large nuggets.[2]

The most important Tertiary 'deep leads' of Victoria are at Ballarat. In several mines a succession of four thick basalt sheets, separated by beds of clay, had to be pierced by shafts before the gold-bearing gravels and bedrock were reached. The clays which alternate with gold-bearing sands often hold well preserved tree-trunks and leaf-im-

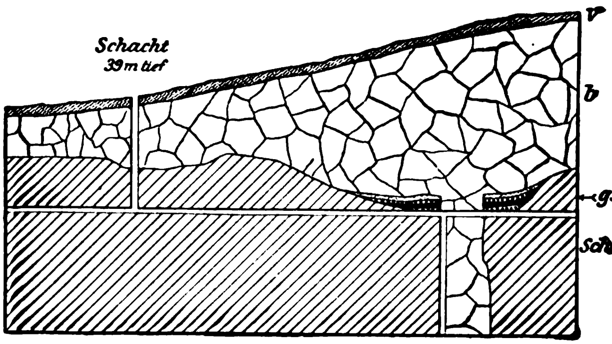


Fig. 257.—Section through Wombat Hill near Daylesford. (H. Louis.) sch, slates; gs, gold-bearing sand and gravel; b, basalt; v weathered layer.

pressions, or even streaks of lignitic brown coal. In some instances the mine workings have disclosed the necks or dikes of basalt that fed the lava flows and intrusive sheets, as is shown in the profile of the mine at Wombat Hill, reproduced in Fig. 257.

Both the alluvial and Tertiary placers of Victoria contain cement deposits, which closely resemble the ordinary pay gravels, but are firmly cemented by a matrix of limonite. These deposits usually rest directly on bedrock.

It is noteworthy that many of the gold placers of Victoria carry cassiterite.

In 1894, when placer mining in the colony was still actively carried

[1] T. A. Rickard: 'Alluvial Deposits of Western Australia,' *Trans.* Am. Inst. Min. Eng. October, 1898, p. 40.

[2] R. Brough Smyth: 'Gold Fields and Mineral Districts of Victoria,' Melbourne, 1869. Phillips-Louis: 'Ore Deposits,' 1896, p. 619. 'Deep Alluvial Mining in Victoria,' F. Danvers Power, *The Engineering and Mining Journal*, 1904, Vol. LXXVIII, p. 509.

on, the total gold output from them amounted to 7,908.9 kilograms, but the production of placer gold has steadily declined, since the average amount of gold in the pay gravel (wash dirt) was about 2 grams per ton in 1894. In the so-called cements it was about 6 grams per ton.

Similar geologic conditions prevail in the gold placers of New South Wales, which in 1894 produced some 2,215 kilograms (71,213 oz.) of placer gold, and in Queensland, which in the same year produced 806.6 kilograms of gravel gold. Gold placers exist also in South Australia, and, as has been found during the last decade, in West Australia. The dry table land of West Australia contains peculiar residual gold gravels, which deserve a somewhat more detailed mention.

From a detailed description accompanied by a full collection sent to the writer by A. Gmehling, it is known that at Kanowna and in the Twenty-five Mile district the older rocks near the gold veins are covered by a mantle of sandstone and agglomerate. These so-called rich cements are rich in kaolin and often in iron, and are worked for gold.

The quartz grains of the sandstone specimens sent to the writer are seen under the microscope to be remarkably sharp-edged splinters, so that in 1898, in a letter to A. Gmehling and in lectures after that, the writer expressed the conjecture that the cements may be eolian formations, developed during the weathering of the older lodes under the influence of the desert conditions of those regions, which with its great contrasts of temperature between day and night promotes the cracking and splintering of the rock. It is a satisfaction to know that this conjecture has been completely confirmed by T. A. Rickard[1] on the basis of his very detailed investigations of the mines.

This investigator studied the Kintore cement deposit, 23 miles northwest of Coolgardie, and another at Kanowna, 25 miles northeast of Kalgoorlie, both of which he regards as débris of weathering, produced in a large measure by the great differences of temperature between day and night and by the strong winds of this dry, almost rainless country. The Kintore cements are derived from the gold quartz veins of the Sugar Loaf mine, which extend past one end of the deposit and in close proximity to it; the source of the Kanowna cements was the White Feather gold vein, outcropping in the immediate vicinity. At Kintore, according to Rickard, the surface of the granite bedrock is marked by pot-holes 2 to 3 ft. across. The rock is overlain first by the gold-bearing sandy cements. averaging 2½ to 5 ft., next by barren 'sand rock' (up to 2 ft.), and finally by a bed of kaolin a few inches to a foot in thickness, the surface being covered with

[1] T. A. Rickard: 'The Alluvial Deposits of Western Australia,' *Trans.* Am. Inst. Min. Eng., 1899, Vol. XXVIII, p. 480.

sand and dust[1]. A few narrow clay bands are intercalated in the sandy masses. At Kanowna, on the contrary, the bedrock is a strongly decomposed diorite. In this rock, a shallow depression, that is 700 ft. by 105 ft., holds at the top a few inches to 2½ ft. of sandy loam worked by the dry blowers, then a layer of detritus (wash), consisting of fragments of ironstone and quartz, imbedded in clay and reaching to a maximum of 25 ft. below the surface. This overlies the cement, itself a bed 6 inches to 5 feet thick, composed of quartz in greenish clay. Near the rim of the trough the quartz occurs in larger, more angular pieces. The gold contents are irregular, but probably averaged about one ounce per ton (31 grams per met. ton). Only the richer parts were at first worked, but later the remnants, carrying $3.05 per ton, were extracted and stamped.

The island of Tasmania also produced placer gold until quite recently, the output for 1894 being 175.2 kilograms.

In New Zealand Tertiary gold placers occur at high elevations, while the recent ones are fluviatile or marine. The elevated placers consist in part of loose gravel and sand, so that they may be worked by the hydraulic method; others are firmly cemented as in the Otago goldfield at Blue Spur. The recent fluviatile placers are almost all situated on Middle Island; both they and the gold-bearing sea-sands are worked by a number of steam dredges. The beach sands are constantly regenerated by the comminuting activity of the surf.

9. *African Gold Placers.*

The gold placers worked at various points by the natives of the Gold Coast of Africa are of slight importance compared to the primary gold vein deposits of that country (see page 519).

Important placer areas occur, however, in the Lydenburg district in the Transvaal especially in Pilgrim's creek and in Blyde valley, which were worked as early as 1873. A residual gold placer occurs at Duivels Kantoor, in the Kaap goldfield of the same colony, where pyrite crystals changed into brown hematite and crystalline gold are found in a weathered débris consisting of still angular fragments of quartz and various rocks. In 1894 the deposit produced 18.6 kilograms of gold. A nugget weighing 1.6 kilograms from that locality was exhibited in Paris in 1900.

10. *Gold Placers of Europe.*

The numerous gold placers of Europe are all now totally exhausted, or yield such minute returns that they are no longer of the least economic importance, though many of them may claim scientific interest.

[1] T. A. Rickard: *Op. cit.*, p. 35.

Among the best known are the gold-bearing alluvial deposits of the Rhine, which were worked by a few gold-washers as late as the forties of the 19th century, between Rheinau, near Rastatt, and Daxlanden, near Karlsruhe. The gold was found concentrated in certain sandbanks, called "gold grounds." According to A. Daubrée[1], gold is also found in older terraces up to 12 kilometers away from the river.

The old gold placers of Bohemia and Saxony and of some adjoining countries are described in F. Posepny's detailed monograph[2].

In Saxony the most important instance is that of the alluvial masses of Göltsch river in the Vogtland, which of late have induced attempts at washing. The collections of the Freiberg mining academy possess placer gold from that river.

Gold was formerly washed in upper Italy, in the valleys of the Dora Baltea, Sesia, Soanna and other Alpine rivers; in Spain on Rio Sil and Rio Duerna in Galicia, as well as in the plain of Granada; in France at Bonnac on the central plateau, and elsewhere.

11. *Theories to Explain the Distribution of Gold in Placers and the Formation of Large Nuggets.*

Various explanations have been given of the fact, observed in so many regions, that the placer gold of the gravels, sands and clays has become concentrated mainly in the lowest layers of those deposits, resting directly on the bedrock, and in some instances has even entered into the outcrops of the rock bottom, so that the upper, crumbly layers of the bedrock may be worked for gold, as is done, for example, in the Ural.

Leaving out of account for the moment the occasional occurrence of large nuggets, to be discussed a little later, the concentration of the finely divided gold at the base of the placers *during* their deposition by rivers is very difficult to explain. A natural concentration, a settling process on a large scale, cannot be assumed, as very properly pointed out by F. Posepny[3], for the reason that the material of the placers usually shows no sorting or classification, but on the contrary proves to be composed throughout its thickness of particles often varying greatly in size and weight. In fact,

[1] A. Daubrée: 'Sur la distribution de l'or dans la plaine du Rhin,' *Ann. des. Mines*, 1846, 4th series, Vol. X, p. 1, and 'Description géol. et minéral. du dép. du Bas-Rhin,' 1852, p. 319 *et seq.*

[2] F. Posepny: 'Die Goldvorkommen Böhmens und der Nachbarländer,' *Archiv f. Prak. Geol.*, 1895, Vol. II, pp. 1–499.

[3] F. Posepny: 'Zur Genesis der Metallseifen,' *Oesterr. Zeitschr.* f. B. u. Hüttenw. 1887, Vol. XXXV, p. 325. Also 'Ueber die Genesis der Erzlagerstätten,' 1894, p. 207 *et seq.*

we know from geological observations that the loose débris forming a placer was not moved or even stirred up by the water all at once, but on the contrary was deposited at different periods, layer after layer.

Posepny's explanation (given on page 621) is regarded as more probable. While according to this hypothesis the concentration of the finely divided placer gold on the surface of the bedrock, or of an impervious intermediate layer, is to a certain degree intelligible as a purely mechanical process *after* the deposition proper, the occasional occurrence of large gold nuggets, such as are very rarely found in lodes, presents further difficulties not met by this theory. The largest gold nugget from the Ural was found in 1842 in the Tsarevo Alexandrovsk placer at Miask, directly on the dioritic bedrock, and weighed 36 kilograms (79 lbs.) It is said to have been surrounded by hard clay. The largest Australian nugget, found at Dunolly in Victoria, and called "Welcome Stranger," was almost entirely free from impurities and weighed 70.9 kilograms. The next largest, "Welcome Nugget," found at Ballarat, at a depth of 54 m. (177 ft.) in 1858, contained 67.3 kilograms of gold. It was apparently waterworn and the gold intergrown with quartz and iron oxide.

At first thought a purely mechanical transportation of the gold from the weathered outcrop of gold lodes or older stratified auriferous deposits appears certain. In fact, the occurrence of large nuggets in gold veins, though rare, is yet a well recognized fact. Thus, according to Newberry, in a quartz vein at the Monumental mine, Sierra Buttes, California, a lump weighing 40 kilograms was found. The nuggets found in placers with gravels and vein quartz attached and intergrown show that large masses can be transported from veins into the placers by purely mechanical processes. Proof of this is afforded by the nugget weighing 40 kilograms discovered by a native in 1851 in Meroo creek in Victoria, which according to Liversidge[1] was still coalesced with vein quartz. This nugget was found on the surface of the earth; in fact, gold nuggets seem to occur at all possible horizons and are to be by no means confined to the surface of the bedrock. The apparently much greater rarity of large nuggets in lodes than in placers is in part explained by the fact that a gravel deposit of any considerable thickness corresponds to a much greater section of a lode (whose destruction occupied thousands of years) than man is ever able to become acquainted with during the working of a mine.

Grave doubts of the purely mechanical origin of placer gold are, however, aroused by a comparison of the nuggets of veins with those found in placers. The former invariably represent crystalline aggregates, usually intimately intergrown with quartz, showing many projecting spurs and

[1] Liversidge: 'The Minerals of N. S. Wales,' 2d ed., p. 67.

sheet-like offshoots. Moreover, the gold is low grade, being strongly alloyed with silver. During transportation in water, by the current of a brook or river, and mixed with vast quantities of cobbles and sand grains, pounding and rubbing against the gold and each other, it seems certain that these projections must be rubbed off and the lumps would finally assume a rounded form and smooth surface. In fact, nuggets are often found in placers which bear out these assumptions. We have seen pebble-shaped nuggets from West Australia, and T. Egleston[1] has described some from Venezuela. The West Australian nuggets which were submitted to us for examination by Mr. Gmehling showed a distinct rounding along the periphery at all the projections and edges, while in the re-entrant angles traces of the original jagged structure of vein gold had been preserved. The great majority of the nuggets found in gravels, however, differ from vein gold in the following points:

(1) Their surface is very irregular, covered with warts or nipple-shaped growths, which do not harmonize with a pebble-like character, but rather suggest a concretionary origin.

(2) They are but rarely mixed with quartz, which appears quite inexplicable, especially for the very large nuggets, if they are regarded as mechanically transported vein gold.

(3) Their fineness in most cases is much higher than that of vein gold. According to Posepny the placer gold of the Ural contains 91 to 99%, the vein gold only 86.6%.

As regards (3), it must be admitted that the number of observations made is as yet much too small to be conclusive. Moreover, in making such comparisons, too much stress must not be laid on the fineness as ascertained on a large scale in stamp-mills. The gold obtained from veins is too easily mixed with traces of other metals occurring in such lodes.

These facts led F. A. Genth, O. Lieber, A. R. C. Selwyn, M. Laur and later T. Egleston, C. Newberry, Daintree and others to the hypothesis that the gold of the gravels, especially the nugget gold, was for the most part deposited from solutions which had circulated through the beds of gravel and sand. It is thought that either the fine "dust" introduced mechanically and uniformly distributed through the placers was dissolved and afterwards redeposited in certain layers or about definite centers, or else that gold-bearing solutions, formed during the decomposition and weathering of the lode, were carried to the placer by ground-water currents.

A fourth reason, not very weighty, it is true, is drawn from observations,

[1] T. Egleston: 'The Formation of Gold Nuggets and Placer Deposits,' *Trans.* Am. Inst. Min. Eng., 1881, Vol. IX, p. 633.

which it is difficult to verify, that placer gravels after working become after some time richer again.

The fact that gold-bearing solutions actually do circulate in placers seems proved by the existence of unquestionably newly formed auriferous pyrites in placer gravels. In the Ballarat goldfield H. A. Thompson found crusts of auriferous pyrite around roots and branches of plant remains. Crystallized iron pyrites on a piece of wood in a placer, directly under an overlying basalt sheet at Ballarat, gave 0.12% gold. One specially convincing example is the auriferous character of iron pyrite found in the middle of an old tree-trunk found in a placer of that locality. This pyrite held 46.1 grams of gold per ton[1].

Roots of trees in the gossan of gold veins are also sometimes coated with gold, as shown by the samples from the Great Boulder Main Reef of West Australia, exhibited in Paris in 1900.

When, moreover, small quartz pebbles are seen to be cemented by gold, as is the case with a specimen at Karlsruhe, mentioned by Brauns[2], it is a strong argument for the segregation and deposition of the metal from a solution.

Important evidence, showing that gold passes into solution in the outcrops of primary deposits, and may in this shape be carried to and through placer deposits, has been furnished by the observations of Lungwitz[3] in the goldfields of Omai, in British Guiana. The ashes of trees that had grown on the goldfield contained a slight amount of gold content, the percentage being decidedly greater in the material from the upper part of the trunks close to the branches, and including the stubs of the branches, than in that from the lower part. He infers that the water absorbed by the roots of these trees contained gold. This agrees with observations upon the placers of that locality, which, contrary to the usual rule, are richer in the upper layers than in the lower. The upper layers, not having been exposed so long, are not leached out to the same extent as the older, lying at the base of the placer. Should these statements be corroborated by analogous investigations, they will be of great importance.

That gold occurs in solution in nature outside of veins is shown by its presence in sea-water, as proved by Sonstadt[4]. According to him, sea-water contains 0.06 grams of gold per ton. This is confirmed by the detailed investigations of A. Liversidge. According to him, the sea-water

[1] Phillips-Louis: 'Ore Deposits,' 1896, p. 631.

[2] R. Brauns: 'Chemische Mineralogie,' 1896, p. 406.

[3] E. E. Lungwitz: 'Ueber die regionalen Veränderungen der Goldlagerstätten,' Thesis Rostock, Leipzig, 1899.

[4] *Chemical News*, Vol. XXVI, p. 159. *Amer. Chemist.*, Vol. III, p. 206.

along the coast of Australia contains 130 to 260 tons of gold per cubic mile of ocean, that is to say, 0.03 to 0.06 grams per ton[1].

The solubility of gold in various saline solutions such as occur in nature, in very dilute form, was studied experimentally by T. Egleston (*l. c.*). He found, for example, gold to be soluble in a solution of ammonium nitrate mixed with some ammonium chloride, and also with sodium and potassium sulphates. H. Wurtz had previously demonstrated the solubility of gold in ferrous chloride and in ferric sulphate. At any rate, the facts show that in nature gold may pass into solution, especially during the weathering of gold veins, where sodium chloride, free sulphuric acid and manganese oxide (haussmannite) may occur side by side, so that even free chlorine may be formed. Organic solvents do not appear to be indispensable, as supposed by E. E. Lungwitz.

On the other hand, the precipitation of the gold from solutions within the gravels offers but little difficulty. Egleston proved by numerous experiments that organic compounds, such as occur in river-water and in ground-water, are able to reduce metallic gold from solutions. Thus, for example, bits of peat introduced in gold solutions induced a precipitation of metallic gold. As drift deposits very frequently contain not only pieces of wood, as observed in California and Australia, but also other vegetal detritus, and as, moreover, the gravels are occasionally overlain by a cover of peat, as in the Ural or in Siberia, and as the ground-water traversing those masses of drifts must constantly receive admixtures of organic acids from growing peat bogs, the precipitation of gold from solutions within the placers, or at any rate a growth of gold around grains or nuggets of mechanical introduction, is certainly, to say the least, well within the range of possibility.

According to H. A. Gordon[2], a notable precipitation of gold in alluvium requires special conditions not everywhere present, such as aridity and hot climate, which prevent the gold solutions furnished by nature from being washed down into the sea and enable them to be concentrated. Such conditions prevail, for example, in Queensland and West Australia and in New Zealand in the dry Otago region. In the latter region, especially in the Upper Tairi district, considerable quantities of "wire gold" were occasionally found, always on the surface of the ground or directly under it. The earlier prospectors looked upon it as roots of grass fossilized into gold. McKay saw a sample of it at Naseby in 1881, weighing 1.2 kilograms. It consisted of thin, straight or bent wire. One side was smooth or striated,

[1] A. Liversidge: 'Gold and Silver in Sea-water,' *Journ.* of the Royal Society of N. S. Wales, 1895, Vol. XXIX.

[2] 'Hysteromorphous Deposits (etc.) in New Zealand,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, p. 292.

the other was covered with small, cubical gold crystals. There seemed to be no possibility that these finds might be derived from denuded lodes.

As the matter now stands, the view expressed by Cohen[1] in 1887, after a critical discussion of all the works then in existence on this subject and subsequently supported by Posepny[2], is still valid, "that by far the larger part of the detrital gold became liberated by the mechanical destruction of older deposits and was mechanically deposited, but that on the other hand a segregation from solutions undoubtedly occurs, though it plays but a subordinate part."

(e) Platinum Placers.

1. *Platinum Placers in the Ural*[3].

The most important platinum-bearing placer deposits of the Ural are those of Goroblagodat, Nizhne Tagilsk and Bisersk. The placers are situated mainly in the basins of the Iss and Tagil rivers, tributaries of the Tura, in the basin of the Vyja.

In the Tagil region, the platinum deposits occur about Mount Soloviov, in the valleys of the Chaush, which runs northward from that mountain stock, that of the Vyssym running west, and that of the Martyan running south. Mount Soloviov consists of peridotite, while the adjoining rocks to the east consist of gabbro-diorite and diorite. The olivine rock passes into olivine gabbro and into various diallage rocks, and has in many cases been altered to serpentine. That all these olivine-bearing rocks are the mother rocks of the platinum (see page 15) is proved by ore-dressing experiments that have been made on a large scale. Per contra, Saytzeff states that, while the peridotite is the chief source of the platinum, the metal is also present in the syenite. This statement is surprising and needs confirmation, but is in accord with recent observations of Kemp and of Brock in British Columbia. It should be observed that not all the peridotite masses of the Ural contain platinum. A very good review of the occurrence of the Ural platinum deposits, with a full list of recent publications, is given by Purington[4].

[1] E. Cohen: 'Ueber die Entstehung des Seifengoldes,' *Mittheil.* des naturw. Vereins f. Neuvorpommern u. Rügen, 1887, Vol. XIX.

[2] F. Posepny: 'Genesis der Erzlagerstätten,' 1894, p. 203.

[3] Bourdakoff and Hendrikoff: 'Description de l'exploitation de platine,' translated from the Russian by G. O. Clerc. Ekaterinburg, 1896. A. Saytzeff: 'Die Platinlagerstätten am Ural' (in Russian). Tomsk, 1898. C. W. Purington: 'Platinum deposits of the river Tura,' *Trans.* Am. Inst. Min. Eng., February, 1899, Vol. XXVII, p. 440. J. F. Kemp: 'The Geolog. Relations and Distributions of Platinum and Associated Metals,' *Bull.* No. 193, U. S. Geol. Survey, 1902, p. 95, with full bibliography.

[4] *The Engineering and Mining Journal*, May 5, 1904, p. 720.

Both the size and the form of the platinum found in the placers changes downstream. Farthest upstream the metal occurs in small nuggets, often angular and rough, and not infrequently coated with a film of ferric hydrate ("platinum in the cap"). It is only in this head-water area that nuggets have been found, the largest one known weighing nearly 10 kilograms (22 lbs.). Farther downstream, the platinum occurs in rounded or flat grains with smooth surface. Some of the grains are found still intergrown with chromite, the companion mineral of platinum in the peridotite and other olivine rocks.

Placer platinum is always impure, and the chemical composition varies for each locality. It contains 51.5% to 86.5% of platinum, with 5% to 13% of iron, and some gold, iridium, rhodium, palladium, osmium and copper. The following analyses of placer platinum from the Ural and from three localities in North America are after Deville and Débray[1] (I-III) and G. C. Hoffmann (IV)[2]:

	I. Ural.	II. California.	III. Oregon.	IV. British Columbia.
Platinum	76.40	85.50	51.45	72.07
Gold	0.40	0.80	0.85	......
Iron	11.70	6.75	4.30	8.59
Iridium	4.30	1.05	0.40	1.14
Rhodium	0.30	1.00	0.65	2.57
Palladium	1.40	0.60	0.15	0.19
Copper	4.10	1.40	2.15	3.39
Irodosmine	0.50	1.10	37.30	10.51
Sand (chromite, etc.)	1.40	2.95	3.00	1.69
	100.50	101.15	100.25	100.15

Besides the platinum and the chromite already mentioned, the platinum placers of the Ural contain some iridium, irodosmine and usually also gold.

The platinum in the placers is concentrated on the bedrock, especially where that surface is rough, a corroded limestone offering specially favorable substratum for placers. The richest placers are found in expansions of the valleys.

The platinum sands washed in 1892 contained on an average 3.3 grams of platinum per ton. Since then the washing of even poorer sands has been taken in hand.

Part of the placer gravel is of a residual character. Thus in all the innumerable gulleys radiating from Mount Soloviov, the talus fragments which have slipped but a few meters down the slope are gathered and taken down the valley to be washed for platinum.

[1] Deville and Débray: *Ann.* Chim. Phys. (3) 56, p. 449.

[2] Cited by J. F. Kemp, p. 50.

In the true alluvial placers the material varies from coarse to fine, according to the location. The overburden is sometimes so thick that bedrock drifts have to be driven underground. An average section of the platiniferous alluvium in the valley of the Iss, after A. Saytseff, is as follows:

'Turfa' { real turf (peat), whence the designation 'turfa' originated, and sand; sandy clay; blue-gray tough clay.
'Ryetchnik,' that is to say, river sand and gravel with large pebbles, without platinum.
Platiniferous sand, 0.7–1.4 m. (2.3–4.6 ft.) thick.
'Potchva,' that is, bedrock.

Sometimes the platiniferous gravel is cemented into a conglomerate. The horizontal distribution of the pay streak varies greatly. Two platiniferous layers have sometimes been found one above the other in the same placer, as in the washings of Alexei-Olginsky, on the Little Osokina.

The platiniferous deposits are in part of Pleistocene age, as proved by tusks and bones of the mammoth in the 'ryetchnik' of the Bokovoi and Yelizavetinsky placers. The Ural placer deposits have been subjected to protracted degradation and represent the remains of vast rock masses destroyed in the course of many thousands of years, during which the minute platinum content of the peridotites was subjected to repeated or continuous concentration, longer than in other regions of the globe.[1]

In the Ural, platinum was first found in 1819 in the gold placers of Dakovlev. Since the discovery of platinum in the district of Nizhne Tagilsk in 1825, up to 1892 a total of 113,211 kilograms of that metal were obtained in the Ural[2]. In 1898 the platinum production of the Ural was 6,027.2 kilograms, in 1901 it was 6,328 kilograms.

2. *Occurrences of Platiniferous Gravels Elsewhere.*

On the Pacific coast of America, sea sands and river gravels, colored black by magnetite and menacconite, contain some platinum, iridium and osmium, together with gold, as in the vicinity of Klamath river in Siskiyou county and in Humboldt and San Francisco counties in northern California and in Oregon. A few hundred grams of platinum ("white gold" of the miners) are obtained every year.

Platinum occurs in commercial quantity, according to Day[3] and Kemp[4] in the placers of the Tulameen river near Princeton, in British Columbia.[5] The nuggets sometimes contain intergrown chromite, olivine and augite.

[1] Kemp: *Op. cit.*

[2] 'The Mineral Industry,' 1894, p. 596.

[3] D. T. Day: 'Notes on the Occurrence of Platinum in North America,' *Trans.* Am. Inst. Min. Eng., Feb. 1900.

[4] *Op. cit.*, p. 47.

[5] R. W. Brock: *The Engineering and Mining Journal*, Vol. 77, p. 280.

The mother rocks of the metal are, according to Kemp, the peridotite, dunite and pyroxenite, which outcrop on the upper course of the river. A slight amount of platinum was discovered along a belt of crushed granite heavily stained with chlorite.

It must be noted that specimens were found which were mechanically intergrown with gold and at the same time had adhering to them remnants of dolomite and magnesite.

Very slight quantities of this metal were obtained from some gold placers of Canada, such as those of Loup river, close to its junction with the Chaudière.

The Colombia, South America, platinum placers are second in importance only to those of the Urals. The platinum comes from the west or Pacific coast area, mainly from the placers of the watershed between the Cauca and Atrato rivers due west of Bogota. The platinum occurs associated with gold, chromite, magnetite and menacconite, nuggets showing it firmly intermingled with gold and chromite. Platinum was first recognized as a new native metal toward the middle of the 18th century in placer gold from Colombian placers, being called platina because of its resemblance to silver (plata).

According to Boussingault[1], platinum has also been obtained from auriferous quartz veins in syenite gneiss at Santa Rosa, in the Colombian province of Antioquia.

Platinum is also known to occur in the gold washings of the Taqui river, on the island of San Domingo.

In New Zealand, platinum has been found associated with gold, osmium and iridium in the gold-bearing placers, though in small amount. It has been found in the beach sands and in river gravels in the southern part of the middle island, notably on the east coast of Otago, on Clutha river and in the Nelson gold district. The Round Hill Gold Mining Company at Orepuki, on Colac bay, obtained up to 1898 about 900 grams of platinum.

Platiniferous sands have also been found in Tasmania.

On the continent of Australia, platinum is known in the gold placers of Fifield and some other points in New South Wales[2]. In 1894 about 31 kilograms (1,093 oz.) of this metal were washed out. Platiniferous sea sands are also found in the same colony on Richmond river.

In Europe platinum occurs, but very scantily, as, for example, in the gold placers of Ollalipian, in Transylvania.

Finally mention may be made of the occurrence of platinum in some

[1] *Ann.* Chem. et Phys. 1826, Vol. XXXII, p. 204.

[2] J. B. Jaquet: 'The Occurrence of Platinum in New South Wales,' *Records* Geol. Survey of N. S. W., 1896, p. 33.

gold placers of Borneo[1]. It is found associated with a good deal of magnetite and blue-gray corundum, as well as with diamond and the exceedingly rare mineral laurite (ruthenium-osmium sulphide). It was first discovered in 1831 in the gravels of Gunung Lawack, southeastern Borneo.

(f) The Copper Placers of the Philippines and Argentina.

According to the verbal statements of F. V. Voit to the author, native copper is found at several points in the basin of the Malaguit, near Paracale, in the province of Camarines Norte, on Luzon. The natives have frequently offered for sale copper sands obtained from the river beds. The copper occurs in fine grains, associated with magnetite, hematite and some gold, the grains varying in size from a millet seed to that of a match-head, and are covered by a brownish-red or blackish crust of oxidic compounds. According to F. Rinne[2], who subsequently examined the locality, the grains for the most part have an irregular prickly surface. Small specimens in the form of threads or cylinders were also observed. With the copper were occasionally found small granules and crystals of iron pyrite, and abundant minute zircons. A very important observation made by F. Rinne is to the effect that, in the brooks at Submaquin and at Calaburnay, many pebbles have a friable crust of cellular-spongy copper, which readily crumbles into copper sand. He justly infers that the native copper of those placers has probably not been transported far, but owes its origin to local processes of reduction of copper solutions by means of organic substances.

True copper placers were described by V. Novarese[3] from Santa Catalina in the northernmost part of Argentina. They consist of unstratified conglomerates of schist and graywacke pebbles, with nodules of oxidic copper ore, which enclose native copper in their center. This deposit, which at the same time is somewhat auriferous, is overlain by non-copper-bearing gold gravels of Pleistocene age.

[1] Th. Posewitz: 'Das Diamantenvorkommen in Borneo,' *Jahrb.* d. k. unga. Landesanst., Vol. VII.

[2] Rinne: 'Kupferreiche Sande im Malaguitgebiet bei Paracale,' *Zeit. f. Prak. Geol.* 1901, p. 387.

[3] Novarese: 'Sui giacimenti auriferi della Puna di Jujuy,' *Rivista* del Serv. Minerar pl 1890.

GENERAL ADVICE TO THE PROSPECTOR.

Those who have read attentively the descriptions herein given of the different types of ore deposits and of the changes which take place in the outcrops of such deposits through weathering, and who have also visited various ore deposits, will hardly need any general directions in prospecting for undiscovered deposits. However, many readers desire a brief summary of the leading facts which a study of ore deposits shows to be of importance to the prospector. The working of discovered deposits belongs to the province of mining and engineering and hence need not be discussed here.

Of all the older so-called prospectors' guides, the brief, simple and concise work of B. von Cotta[1] is still the best, and we shall be able in many instances to follow his clear exposition, excellent especially for its brevity and simplicity. Many good hints are also contained in the recently published work by R. H. Stretch[2].

Such hints are necessarily always of a very general nature. Special rules cannot easily be given, since they would have to be as varied as the geologic nature of the deposits described by us.

It is well known, however, that many ore deposits were discovered by accident, when nobody was looking for them, and furthermore, that most professional prospectors or ore-seekers in unexplored regions of the globe are not geologists, or at most possess only certain elementary and rather instinctive geologic knowledge. Nevertheless, the rude empiricism so successful in this field may still profit by the guidance of certain geologic facts, as will appear from the following considerations.

ASSOCIATION OF ORE DEPOSITS WITH CERTAIN ROCKS.

Von Cotta's leading principle, that "Ore deposits in a general way are found more frequently in regions of older than in those of newer rocks," is still valid. The reason of this, as explained by him, is not that older geologic periods presented more favorable conditions for the formation of

[1] B. v. Cotta: 'Die Lehre von den Erzlagerstätten I,' 2d ed., Freiberg, 1859, pp. 224-236.

[2] R. H. Stretch: 'Prospecting, Locating and Valuing Mines,' New York and London, 1899. C. W. Moore: 'A practical guide for prospectors. explorers and miners,' London, 1893. S. H. Cox: 'Prospecting for minerals,' practical handbook, revised edition, 1900.

ore deposits, but that most of the ore concentrations can take place only in the deeper regions of the globe, under higher temperature and higher pressure than prevail at the surface. This is true not only of all the deposits that have to be regarded as magmatic segregations or as contact-metamorphic formations, but also of most true veins and other epigenetic formations. Only the purely sedimentary ore deposits, and those secondary deposits that were laid down far from the original source of their ores, are exceptions. But all those older parts of the earth's crust that have been subject to those conditions must formerly have borne a heavy cover of younger strata, from which they were exposed only by subsequent erosion. This of course is possible only when they themselves possess a high geologic age.

Usually the country rock of the ore deposits, if not crystalline from the start and thus proof against most plutonic changes, bears traces of the effect of the chief factors concerned in the concentration of ores, namely, high pressure and temperature; that is to say, the rock appears more or less metamorphosed. Thus the metamorphic schists always offer to the ore-seeker a particularly favorable field; he will have to direct his steps toward those regions where those rocks outcrop. It is immaterial whether the crystalline schists belong to the group of Archean schists, admitting of no further determination of age, or whether they have been recognized as metamorphosed Paleozoic sediments.

The possibility of finding ore deposits in such ancient, and especially in such metamorphic, rocks is further increased if certain other conditions prevail. Above all, as a general rule, in regions of geologically ancient sedimentary rocks, those districts are especially favorable which have a mountainous character or had it in former geologic periods, having been more or less planed down by subsequent erosion. This principle is about equivalent to the observation of general geology, that crystalline schists are found mainly in mountainous regions or in degraded tracts that formerly possessed a mountainous character.

The very oldest German writers on mining matters made a distinction among mountains. They preferred "gentle middle mountains and flat valleys" to abrupt, jagged, "piecemeal" mountains of Alpine character, and, on the whole, not without reason. Modern folded mountains—modern in the geologic sense, such as the Swiss Jura, the larger part of the Alps and the Carpathians proper—with their abrupt forms contain on the whole but very scanty ore deposits; on the contrary, the older mountains, especially those whose principal uplifts fall within the Paleozoic period, such as the Erzgebirge and the Hartz, are on the whole much richer in ore deposits, and the same is true of old mountains almost planed down by the activity of water, veritable ruins of mountains, such as the Rhenish Schiefergebirge. The reason of this phenomenon is, that in the more youthful "folded mountains" the real seats of the ore concentrations, viz., the crystalline cores, are not yet sufficiently freed from their vast cover of younger sediments. As a rule, the only metallic treasures of such geologically modern mountain ranges are ore deposits formed syngenetically with the country rock, especially iron ore deposits. (These remarks apply principally to areas of crystalline schists. The great ore deposits of the western United States and Mexico occur in Tertiary rocks and in regions of rugged peaks and high mountains. W. H. W.)

The limits within which the prospector must chiefly rely upon making valuable discoveries is still more closely defined, and his path more clearly apparent, if he remembers that by far the greatest number of epigenetic and of course all magmatic ore deposits are more or less closely connected with masses of eruptive rock.

Throughout this work especial stress has been laid on the significance of the genetic association of ore deposits with plutonic centers, either as the roots of old volcanoes and great intrusive masses which have been exposed by long and great denudation, or in ancient and modern volcanic masses solidified near the surface. Summarized, this association is as follows:

Granites, especially those that contain tourmaline, lepidolite or topaz, one or all, are exceedingly apt to be associated, all over the globe, with tin veins and impregnations. Granites, more particularly aplites, have also in many cases been regarded as responsible for the formation of gold veins. The silver-lead deposits also are probably in many cases in close genetic relation to granitic rocks, as was again proved recently by the detailed study by Dalmer[1] of the Erzgebirge. Lastly, the contact-metamorphic deposits, so varied in their metallic contents, occur on the borders of granitic, syenitic or dioritic masses. We have seen that gabbros, diorites, peridotites and serpentines are connected with deposits of nickel-copper ore; augite-syenites and non-quartzose porphyries with iron ores; diabases and diorites (in part transformed diabases) with gold ores; other diabases and melaphyres with copper ores; dacites and liparites, especially when altered to propylite, with silver-gold ores, etc. Hence the prospector will have to devote special attention to such eruptive masses.

SPECIAL INDICATIONS OF ORE DEPOSITS.

After the general features of a region have been carefully considered in connection with the generalizations just presented, a search must be made

[1] K. Dalmer: 'Westerzgebirgische Granitmassivzone,' *Zeit. f. Prak. Geol.*, 1890, pp. 287-313.

for special indications of ore deposits. In this search the color of the outcrop is of especial importance. This is shown not only in the outcrop when exposed either naturally or by prospecting trenches, but also in the loose, weathered soil, in which it forms a so-called "tail" (Schweif) or fan, that is, an area with illy defined borders in which the gossan colors the ground. In cultivated regions this coloration may be visible even on tilled soil. From what has been said about the gossan (p. 365) and its exceedingly varied development, it may be inferred that this coloring may be of the most diverse character. Brown-red discolorations are the most common, and are due to the most heterogeneous deposits. Where copper compounds are present, blue and still oftener green tones may be developed; yellowish ones indicate lead, whitish ones zinc.

Attention must also be paid to the surface configuration, which often betrays outcrops. When the ore masses consist mainly of a resistant gangue, such as quartz, the outcrops will weather out in the topography as elevations. Veins are thus apt to be conspicuous as reefs or crests, often persistent for long distances. On the contrary, if the predominant gangues are easily leached out, as in the case of carbonate spars, or the vein filling consists almost exclusively of easily decomposable ores, or, finally, if the outcrop is merely a zone of disintegrated rock, not of a true vein, the outcrops form depressions; in such cases the veins on mountain slopes will often coincide with gullies and gulches, since the water cuts easily into the soft zone of weathered material.

The plant growth may also indicate the presence of ore deposits. Certain plants have long been known to botanists and florists in which the color of the petals and possibly other habits undergo marked changes when certain metallic compounds are added to the soil in which they live. Gardeners, for example, use iron oxide to produce certain color variations in *Hortensia*. There are in Nature certain rare instances of particular plants or varieties that are found only in soils containing certain metals. It is true that the data upon this subject, though often mentioned in literature, is in need of critical examination by competent botanists, but certain associations seem to be thoroughly established.

The best known case is that of the calamine violet (*Viola lutea* Huds., *var. calaminaria* Lej.) found on the calamine outcrops of upper Silesia, Westphalia and Belgium, as well as in Utah.

E. Lidgey[1] mentions the following indicative plants: In the limestone soil above galenite beds, in Michigan, Wisconsin and Illinois, the *Amorpha canescens*, a *Papilionacea*, resembling indigo; in the clayey soil with galenite in Missouri, rhus and sassafras shrubs thrive; in Montana the silvery

[1] *Trans.* Austral. Inst. Min. Eng., 1897, Vol. IV, p. 116.

leaved pink flowering *Eriogonum ovalifolium* is common about silver veins (and elsewhere on granite areas. W. H. W.). Finally, according to S. B. Skertchly[1], in Queensland the *Caryophyllacea polycarpæa spirostylis* is said to be an infallible indication of copper in the soil.

As accumulations of ore are often found along lines of displacement, separating two kinds of rock which may be totally unlike, this difference will often find expression in the vegetation. Thus, according to R. H. Stretch[2], in Arizona one finds a monotonous vegetation of yucca on granite, quartzite and other siliceous soils, while areas of clay slate are covered with ocotilla, and the limestone and the more calcareous eruptive rocks with various species of the cactus family. In California, according to this author, the limits of the gold-bearing gravel beds is shown along the mountain slopes, especially in spring time, by certain white-flowering shrubs, since these water-loving shrubs grow where it oozes out between the gravel and the bedrock, or, at any rate, where it keeps the soil moist. Thus a good observer will be careful to note the floral peculiarities of a region.

The facts just mentioned leads us to the indication afforded by springs. Every well-digger knows that springs are especially apt to emerge where fissures traverse the ground, and thus vein outcrops may be indicated by zones of springs. "Every lode has its own water" is an old miners' saying. Sometimes springs issuing from vein fissures carry metallic salts and deposit iron ocher and other metalliferous, muddy decomposition products, the so-called *guhrs*, which indicate the presence of veins close at hand.

A positive proof of the presence of ore deposits near by is the occurrence of the scattered débris from such deposits, commonly called "float" by the prospector. It is found either mixed in the débris on slopes or in the gravels of brooks and river beds. This float commonly consists mainly of gangue, more rarely of metallic minerals, though traces of the latter are often found in the ore pebbles. Quartz, especially lode quartz, which is generally easily recognizable by its corroded appearance, should be carefully looked for. The characteristic metallic minerals associated with ores will often afford useful information to one who knows the paragenetic conditions of ore deposits. The prospector must follow up the streams carrying vein quartz or other gangue, to and along their head-water branches, until a point is reached where the float is no longer present in the bed, and must look then for the vein on the slopes on both sides, or in the bed of the stream. In a similar way the slopes must be examined until fragments of ore or gangue can no longer be seen. It is then probable that the observer

[1] *Gardeners' Chronicle*, Dec., 1897.

[2] 'Locating, Prospecting and Valuing Mines,' etc., p. 152.

is above or higher up the slope than the vein outcrop, and trenches must be dug accordingly.

In prospecting veins it is a great advantage to one to have some knowledge of the prevailing strike of the veins of a region. The prospector ought therefore to carefully observe and record the strike and dip of all strongly marked, even though barren, fissures, in order to obtain the general direction of strike of the veins. This is easy enough if barren quartz veins occur, as they can usually be traced, and the prospecting trenches must then be made as nearly as possible at right angles to this general strike. If it is not possible to obtain such preliminary knowledge, the trenches must be dug in two directions, at right angles to each other.

On page 52 we have laid stress on the importance of the most accurate knowledge possible of the structural features of a region if one is prospecting for stratified deposits. In this case the trenching should be done at right angles to the general strike of the beds, or as near it as possible.

It is, of course, apparent that in looking for ore deposits one must keep a sharp lookout for evidences of old, even prehistoric excavations, dump heaps or depressions due to the caving in of old workings. Details on this point may be found in various text books on mining engineering.

In prospecting for placer deposits somewhat different observations are necessary.

In hunting for alluvial gold, platinum or cassiterite, the most essential feature of the outfit is a gold pan, or batea, with a horn (miner's horn spoon), which is easily carried and can be used with very little water, and is thus adapted even to arid regions. The prospector must look for and wash the dark-colored, iron-ore-bearing parts of the sand, especially those which have collected in the depressions of the bedrock or between the heavier boulders. These sands are most apt to contain the precious substances sought for, if they occur in the drift. The best places to search are the convex sides of river bends, or points where the brooks enter a widening of the valley. In any case, very many unsuccessful attempts will have to be made, and even when values are found in one sample many others are still needed to attain definite results. The presence of the substances sought for may be betrayed, even before their discovery, by the characteristic associated minerals previously enumerated; chromite will point to platinum, cinnabar to gold, topaz and tourmaline to cassiterite.

Skilled prospectors are able, from the number of gold particles (colors, called also pintas) glistening in the dark-colored heaviest residue in a pan, to estimate the richness of the placer, and in some cases the minute gold particles invisible to the naked eye are gathered by amalgamation in the pan. For this reason, or on this account, the value of gold placers is not usually given as so much per ton of sand or gravel, but is stated in terms of a definite cubical unit, usually so many dollars or cents per cubic yard, or so much per pan; in California, for example, a cubic yard equals 150 pans, a pan being approximately 25 pounds. When once the auriferous character of a gravel or sand deposit has been recognized, the next task will be to expose its deepest layers, which are usually particularly rich, and in certain cases to obtain an idea of the course and succession of the rich layers (pay streaks). The metal must be looked for in each and every layer, even the uppermost, which is usually decomposed into clay. In making this detailed investigation of a placer, deep test pits will have to be dug or borings made, which should be put down in definite order, usually in rows transverse to the direction of the valley, the results being carefully platted, so that the value and extent of the deposit may be calculated.

A search should afterwards be made for the primary deposits which have supplied the placer. The stream bed above the placer must be carefully examined, and if large and but slightly rolled fragments are found in the stream bed, the search should be conducted with special care, because the deposit may be close at hand.

If the latest formed alluvium is metalliferous, a search should be made for old river terraces, especially elevated gravel and sand deposits of Pleistocene or Tertiary age. These are not infrequently found preserved beneath a protecting cover of basalt. Hence basaltic table mountains or high plateaus, where old river courses are suspected to exist, must be carefully examined. The practiced eye recognizes them from a great distance by their shape. When a country contains placers the sand of its coast may occasionally contain gold or platinum. In testing such sands the blackish particles are most apt to contain the metal.

A special manner of prospecting is used in hunting for deposits of magnetite, and to some extent for those of pyrrhotite. Brilliant success has followed the use of the magnetic compass for the discovery of such deposits, especially since the invention of the Swedish mining compass by D. Tilas in 1672. The method was scientifically elaborated by R. Thalén about 30 years ago, and has been materially improved by E. Tiberg. The description of the Thalén-Tiberg magnetometer and its application may be read in the works cited below.[1] That the usefulness of the method is by

[1] R. Thalén: 'Redogörelse för en ny method att medelst magnetiska mätningar undersöka jernmalmsfält,' etc. Övers. Kongl. Vet. Ak. Förh., 1874, part II, p. 5. See also part IV, p. 7, part VIII, p. 3. E. Tiberg: 'Om magnetiska mätningar vid jernmalmsfält medelst den magnetiska inklinationsvagen,' Jern-Kontorets *Ann.*, 1884, pp. 29-67. H. Lloyd Smyth: 'Magnetic Observations in Geological Mapping,' *Trans.* Am. Inst. Min. Eng., Sept., 1896. G. Nordenström: 'Dans L'Industrie Minière de la Suède en 1897,' Stockholm, 1897, pp. 20-30. Th. Dahlbloom: 'Ueber magnetische Erzlagerstätten und deren Untersuchung durch magnetische Messungen,' translation

no means confined to iron ores in northern regions is proved by its successful application by K. Johansson to the ore field of Marbella, Estepona and El Pedroso in southern Spain, and recently also with specially sensitive instruments by P. Uhlich at the nickel-ore deposit of Sohland, in Lusatia. It has a great future before it, and it may be said that for magnetic iron-ore deposits the divining-rod has been resurrected in scientific form.

THE TAKING OF SAMPLES FOR SCIENTIFIC PURPOSES.

When the prospector has found an ore deposit and has done the first development work he should carefully sample it. The method of doing this is given in books on assaying[1], and hence need not be touched here. Another kind of sampling, however, may well be described here, namely, that which is to furnish the basis for a scientific geologic description of the ore occurrence. This is lamentably unfamiliar even to otherwise well trained miners and explorers. The following rules should, so far as possible, be observed when sampling a deposit for this purpose:

(1) First of all, make a sketch of the occurrence, even though on the crudest topographic basis, denoting on it by figures the points from which the several samples were taken.

(2) The corresponding numbers should be at once attached to the sample by means of labels, or, better yet, painted on with cinnabar color when this is possible. These figures are rendered still more indestructible by a varnish of ordinary shellac. The samples should be accompanied by cards bearing the same numbers, or by a corresponding list.

(3) A cross-section, be it ever so simple, should always be added, and should be inscribed with the corresponding figures.

Next collect:

(4) Samples of the undecomposed ore from the deep portion of the deposit; also of the decomposed outcrop.

(5) Fresh country rock outcropping at some little distance, and perhaps also decomposed country rock immediately adjoining the deposit from both the underlying and the overlying beds, in hand specimens and also in smaller fragments, suitable for chemical or microscopic examination.

(6) The same from eruptive dikes or masses outcropping in the vicinity.

of P. Uhlich, Freiberg, 1899. P. Uhlich: 'Ueber magnetische Erzlagerstätten und deren Untersuchung mittelst des Magnetometers,' *Jahrb. f. d. Berg- u. Hüttenw.*, Freiberg, 1899, pp. 1-43, and 'Weitere Beitr. zur. Aufsuchung magnetischer Erzlagerstätten,' same place, 1902, pp. 98-128. Magnetometers can be obtained from Berg of Stockholm or Pässler of Freiberg.

[1] B. Kerl: 'Probirbuch,' third edition, 1894, p. 2 *et seq.*

(7) Fossils from the fossiliferous underlying and overlying strata, when such strata are present.

(8) Samples of clayey, gougy and gravelly masses connected with the deposit, material to which assayers, too, should pay close attention, despite its apparent worthlessness (for instance, the argentiferous gouge of many occurrences).

(9) In the case of placers, both crude and washed or concentrated material, should be packed in sacks, and, when possible, samples of each layer of the cross-section of the placer.

A small but well selected and labeled collection of this kind may be of greater scientific and perhaps also of more practical value than a large collection assembled without method and improperly labeled or packed.

Only when real mining is carried on will it finally be possible completely to satisfy scientific demands and to obtain larger samples, showing, if possible, both the structure of the occurrence and both selvages, together with the country rock.

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