that vein-formation, whether on a large or a small scale, is always essentially a process of segregation.

We know that every volcano and every lava-flow must be connected below the surface with a dike; and it is almost equally certain that the waters of mineral springs forming tufaceous mineral deposits on the surface, as in the geyser districts, also deposit a portion of the dissolved minerals on the walls of the subterranean channels, which are thus being gradually filled up and converted into mineral veins, which will be exposed on the surface when erosion has removed the tufaceous overflow.   This connection of vein-formation with the superficial deposits of existing springs has been clearly proved in several important instances in Nevada and California.

Veins occur chiefly in old, metamorphic, and highly disturbed formations, where there is abundant evidence of the former existence of profound fissures, and in regions similar to those in which thermal springs occur to-day.

External Characteristics of Veins. — The typical vein, in its simplest form, is well represented by several specimens in the upper part of section 7[1], straight and regular cracks in slate and other rocks having been filled by the infiltration of calcite and quartz.   In other words, a typical vein may be described as a fissure of indefinite length and depth filled with mineral substances deposited from solution.   Externally it is very similar to the typical dike, for the fissures are made in the same way for both. Veins are normally highly inclined to the horizon; they

[1]Sections 7 and 8 are to be regarded as one, with one series of numbers; the odd decades on the left and the even decades on the right.

exhibit in nearly every respect the same general relations as dikes to the structure of the enclosing or country rock; and the ages of veins are determined in the same way as the ages of dikes.

Other specimens in this section show less regular veinlets of quartz and calcite in slate, sandstone, and marble, illustrating on a small scale the branching and other normal and common irregularities of veins.

Veins are the chief repositories of ores; and the extensive mining operations to which they have been subjected in all parts of the world, have made our knowledge of their forms below the surface very full and accurate. It has been learned in this way that very often the corresponding portions of the walls of a vein do not coincide in position, but one side is higher or lower than the other, showing that the walls slipped over each other when the fissure was formed or subsequently; and this faulting or displacement of the walls appears to be much more common with veins than with dikes, perhaps because the fissures remained open much longer. This differential movement of the walls is the principal cause of the almost constant changes in the width of veins. For, since the walls are never true planes and are often highly irregular, any slipping of one past the other must bring them nearer together at some points than at others. This occurs chiefly with large veins, and hence is not easily shown in a collection. As a rule, the enormous friction accompanying the faulting either crushes the wall-rock, or polishes and striates it, producing the highly characteristic surfaces known as *slickensides*; a feature which is commonly observed with joint-structure and will be fully illustrated in that connection, only two small slickensided veins of quartz (**28–29**) being shown here. When the wall is finely pulverized in this way, or is partially decomposed before or after the filling of the fissure, a thin layer of soft, argillaceous material is formed, separating the vein proper from the wall-rock. The

miners call this the *selvage*; and it is a very characteristic feature of the large fissure veins, but is rarely observed in the smaller examples, such as must be used for illustrations.

Fragments of the wall-rock are frequently enclosed in veins, as may be seen in several of the specimens already referred to and especially in the irregular vein of calcite in trap (**13**) and the piece of lead and zinc ore from Kansas (**14**), and the veins sometimes branch or divide in such a way as to enclose a large mass of the wall, which is known as a "horse" (**4**). A similar result is accomplished when a fissure is reopened after being filled, if the new fissure does not coincide exactly with the old. This also is a feature to be observed chiefly with large veins; but something of it can be seen on the left side of the beautiful section of a rhodochrosite and quartz vein from Montana (**22**). It has been proved that veins have thus been reopened and filled several times in succession; and in this way fragments of the older vein material become enclosed in the newer.

Although usually determined in direction by the joint-structure of the country-rock, veins are often parallel with the bedding, especially in highly inclined, schistose formations. Such interbedded veins are commonly distinctly lenticular in form, occupying rifts in the strata which thin out in all directions and are often very limited in extent. The little vein of quartz in mica schist (**15**) is in nearly every respect a typical example. Among the illustrations of dikes (page 218) we have seen that the eruptive material has in some cases penetrated in thin sheets along all the bedding-planes of thin-bedded, shaly or foliated rocks, giving rise to a minute interlamination of rocks radically distinct in origin. A precisely similar relation is often observed between veins and the enclosing rocks. The specimen

from Somerville (**45**) shows such sheeted veinlets in a trap rock which has been foliated by the development of slickensides in it; while the mica schist (**46**) shows the same thing for a foliated sedimentary rock; and the streaks of slate in the section of the auriferous quartz vein from Nova Scotia (**44**) require a similar explanation.

Whether conforming with the joint-structure or bedding, veins are commonly arranged in systems by their parallelism, those of different systems or directions usually differing in age and sometimes in composition, and the older veins being generally faulted or displaced when intersected by the newer. The small veins of calcite in slate from Somerville (**11**), and of fibrous gypsum in earthy gypsum (**16**), are examples of parallel veins; and the polished specimen from Vermont (**24**) is a very neat illustration, on a small scale, of two distinct systems of veins.

In this instance, however, the systems are of the same age and composition, the two series of cracks in the black slate having been filled simultaneously with finely fibrous calcite. The fissures in this specimen are intersecting, but the veins are not strictly so.

Internal Characteristics of Veins. — Internally, veins and dikes are strongly contrasted; and it is upon the internal features, chiefly, as previously explained, that we must depend for their distinction. In metalliferous veins the minerals containing the metal sought for (the galenite, sphalerite, etc.) are the *ore*; while the non-metalliferous minerals (the quartz, feldspar, calcite, etc.) are called the *gangue* or vein-stone proper.

This distinction is illustrated by several of the specimens. One of these (**21**) is a polished section of an English lead vein, in which the purple fluorite and yellow barite forming the main part of the vein are the gangue and the ore includes only the dark masses of galenite (lead ore) in the middle of the vein. The section of a vein from Pennsylvania (**23**) shows both lead ore and zinc ore with a quartz gangue.

Although the combinations of minerals in veins are almost endless, yet certain associations of ores with each other and with different gangue minerals are tolerably constant, and constitute an important subject for the student of metallurgy and mining.

When a vein is composed of a single mineral, as quartz or calcite, it may rival a dike in its homogeneity. Most important veins, however, are composed of several or a large number of minerals, which may be sometimes more or less uniformly mixed with each other, but are usually distributed in the fissure in a very irregular manner. The great granite veins which are worked for mica, feldspar, and quartz, are good illustrations, on a large scale, of the structure of veins in which several minerals have been deposited contemporaneously. The individual minerals are found to a considerable extent, in large, irregular masses, with no order observable in their arrangement.

When a mineral is deposited from solution, it crystallizes by preference on a surface of similar composition, thus quartz on quartz, feldspar on feldspar, and so on; and it seems probable that this selective action of the wall-rock may be a principal cause of the irregular distribution of minerals in veins. It has often been observed in metalliferous veins that the richness varies with the nature of the adjacent country rock. This dependence of the contents of a fissure upon the wall-rock may be due in part to the selective deposition of the minerals, and in part to their derivation from the contiguous portions of the

country or wall-rock, as in the so-called segregated veins. Temperature and pressure exert an important influence upon chemical precipitation, and it is, therefore, probable that the composition of many veins varies with the depth.

The most important structure observed in veins is the banding or appearance of stratification which is produced when the mineral matter is deposited in more or less regular layers over the walls of the fissure. This banding may sometimes be observed even when the vein is composed entirely of one mineral, the vein then presenting a double appearance. The little vein of chalcedony from the Bad Lands (**25**) is an example. The specimen shows the entire thickness of the vein, which was formed by the deposition of silica on each side of a crack in the Tertiary marl, the deposition continuing until the two layers thus formed met in the middle in some parts of the fissure; but the deposition of the silica has been followed in the wider parts of the fissure by calcite, giving three distinct bands in all, the calcite forming one double band, and showing what may be regarded as the normal irregularity. Frequently, perhaps usually, the minerals of composite veins, as in this instance, are deposited in succession, instead of contemporaneously, and the number of bands is increased. The first mineral deposited in the fissure forms a layer covering each wall, and is in turn covered by layers of the second mineral, and that by the third, and so on, until the fissure is filled or the solution exhausted. Thus, in the vein of coarse granite from Fitchburg (**30**) we observe between the walls of fine grained granite, on either side, a layer of white feldspar with a little mica and tourmaline, while the middle of the
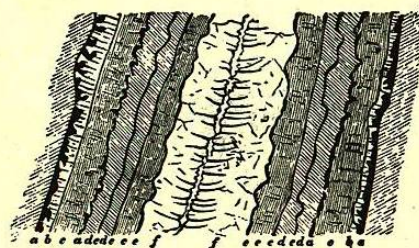
Section of the Prinzen Lode, Freiberg. *a*, Blende; *b*, quartz; *c*, fluorite; *d*, barite; *e*, pyrite; *f*, calcite.
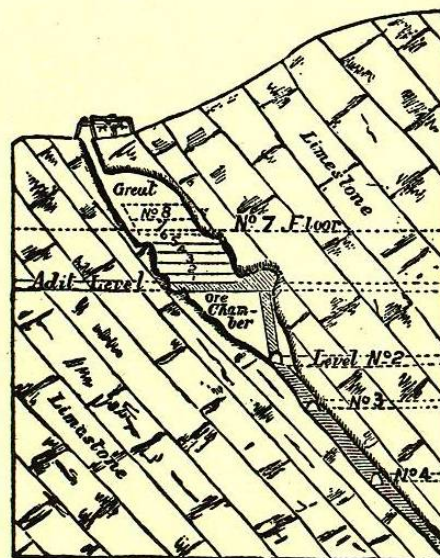
Transverse section of the great ore chamber in the Emma Mine, Utah. 1 inch = 159 feet.

fissure is filled with a solid (double) layer of quartz. And in the specimen from a vein of lead and zinc ore, from Pennsylvania (**23**), we have a complete section showing on each side, first a layer of zinc ore (sphalerite), second a layer of quartz containing some crystalline masses of lead ore (galenite), and then down the middle of the vein a solid layer of finely granular galenite. Still more striking is the polished section of an auriferous vein from Montana (**22**). The first mineral deposited here, evidently, was quartz containing some pyrite, the layer of quartz on one side, as already observed, having been subsequently broken up. Then came in succession more pyrite, the broad bands of rhodochrosite, and narrower bands of quartz. The latter completed the vein at most points, but in the wider parts cavities were still left in which more rhodochrosite was afterwards deposited. This is a very instructive specimen, showing well, among other things, how the normal regularity of the banding is influenced or disturbed by the tendency to crystallization and segregation.

The regular alternation of minerals in a vein is, however, most beautifully illustrated by the polished section from England (**21**). We can count in this, on each side of the middle, no fewer than six layers of fluorite (purple and clear) alternating with five layers of barite (creamy white and buff) ; while a single broken band of galenite marks the central line or axis of the vein.

The barite bands are somewhat interrupted, especially on the right side ; and in this respect and also in the rounded or mammillary outlines of the detached masses, they afford another excellent illustration of the way in which the tendency of the solution

to form continuous layers of each mineral is opposed by the
tendency inherent in the mineral itself to grow independently
of the surface. This principle has a very wide application in
geology; for molecular and mechanical forces are often at vari-
ance and each modifies the action of the other.

Slender or prismatic crystals occurring in veins are
usually perpendicular to the walls of the vein; and a
layer made up in this way of transverse crystals is called
a *comb*. The large specimen of quartz (**41**) is an ex-
cellent illustration of a comb, being part of one side of a
quartz vein; and the next specimen (**42**) representing a
more complex and somewhat broken vein of quartz, illus-
trates various phases of *comb-structure*, including both
single and double combs. In the vein of calcite from
Isle Royal (**12**) the crystals are distinctly prismatic, and
form two combs, separated by a thin layer of iron oxide.
Since the crystals grow from the wall of the vein toward
the middle, the inner surface of each comb must show the
free, growing ends of the crystals, as seen in the specimen
just referred to, and it is easy to see that the crystals of
one comb must often project into or even through the
layer or comb formed next after it, successive combs
being locked together in this way. In the second granite
vein from Fitchburg (**43**) something of this can be seen,
slender crystals of tourmaline starting from the walls and
penetrating the subsequently formed layers of feldspar
and quartz. Still better is the granite vein from Chester-
field on the bottom shelf (**82**) in which slender crystals
of red and green tourmaline pass through the well-defined
layers of lamellar albite (clevelandite) into the layer of
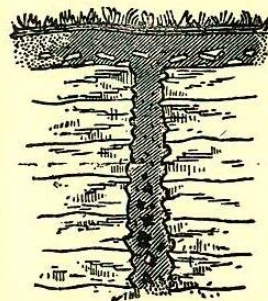smoky quartz forming the middle of the vein.
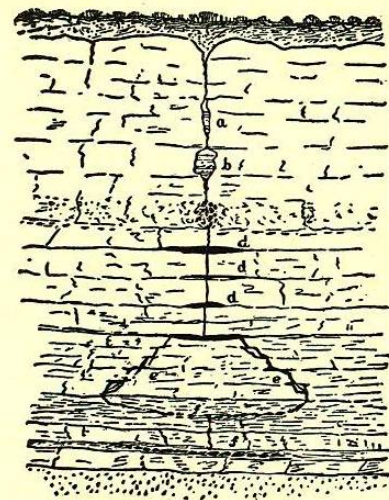
Ideal section, showing characteristic forms in the different horizons
of the lead deposits of Southwestern Wisconsin. *a*, Vertical crevice;
b, cave opening; *c*, tumbling openings; *d*, flat opening; *e*, flats and
pitches; *f*, flats.
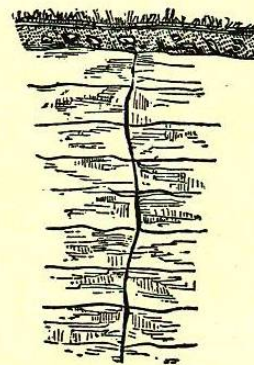
Vertical fissure filled with ore, forming a vertical sheet deposit.
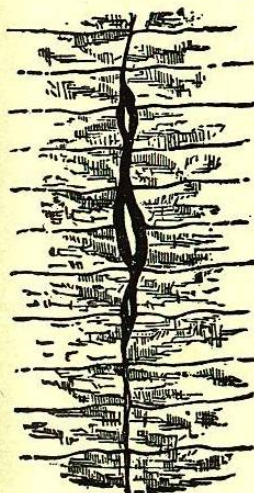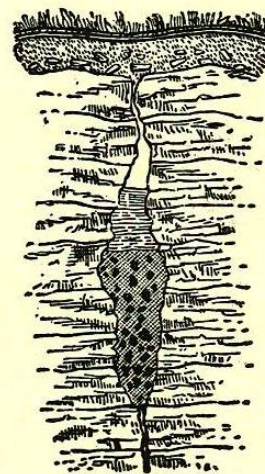
Open crevice, lined with galena.

The same crevice after having undergone some decay, by which the ore was loosened from the walls and mixed with clay.
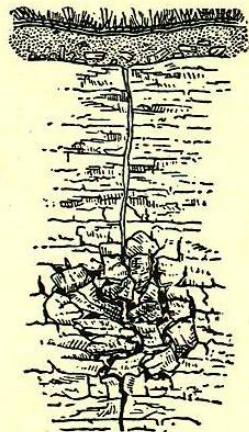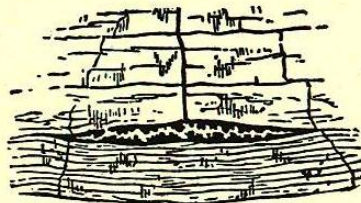

Gash vein.

Gash vein after disintegration.

Breccia deposit. A local breaking up of the beds, forming interstitial spaces in which ore deposition has taken place.

FLAT OPENING.

Flat opening, lined with galena.

This tendency of crystals of prismatic habit to grow perpendicularly to the walls of the vein is seen also in the case of the extremely slender or fibrous minerals, such as asbestus, satin spar (**27**), chrysolite, etc., the fibers being arranged cross-wise in the vein, and the length of the fibers measuring the width of the vein. One of the specimens referred to s a distinctly banded vein, showing two layers or combs.

The various specimens show clearly how the banding of veins may be distinguished from the stratification of the sedimentary rocks. The main points to be observed are the mineral composition, the relations to the enclosing rocks, the repetition of the bands in reverse order on opposite sides of the middle of the vein, and the comb-structure. The banded structure of veins is exactly reproduced in miniature in the banding of agates, geodes, and the amygdules formed in the steam-holes of old lavas.

The unfilled cavities which frequently remain along the middle of a vein (**42**) are called *vugs* or *pockets*. As in the case of geodes, they are commonly lined with crystals, and when the latter are minute, the pockets are called *druses*. In metalliferous veins, the ore is often much more abundant in some parts than in others, and these *ore-bodies* or *pay-streaks*, especially when somewhat definite in outline, are known in their different forms and in different localities, as *courses*, *slants*, *shoots*, *chimneys*, and *bonanzas* of ore. The intersections and junctions of veins are often among the richest parts, as if the meeting of dissimilar solutions had determined the precipitation of the ore. But these features, evidently, do not readily admit of museum illustration.

Metalliferous veins, especially, are usually deeply decomposed along the outcrop by the action of atmospheric

agencies. The ore is oxidized, and to a large extent removed by solution, leaving the quartz and other gangue minerals in a porous state, stained by oxides of iron, copper, and other metals, forming the *gossan* or *blossom-rock* of the vein.

Peculiar Types of Veins and Ore-Deposits. — In calcareous or limestone formations, especially, the joint-cracks and bedding-cracks are often widened through the solution of the rock by infiltrating water, and thus become the channels of a more or less extensive subterranean drainage, by which they are more rapidly enlarged to a system of galleries and chambers, and, in some cases, large limestone caverns. The water dripping into the cavern from the overlying limestone is highly charged with carbonate of lime, which is largely deposited on the ceiling and floor of the cavern, forming stalactitic and stalagmitic deposits. These are masses of mineral matter deposited from solution in cavities in the earth's crust, and are essentially vein-formations.

It appears best, therefore, to class stalactites (**31–36, 71–73**) and stalagmites (**51–53**) as special structural features of veins. But the specimens require no particular explanation, beyond what is given on the labels. Portions of caverns deserted by the flowing streams by which they were excavated, are often filled up in this way, being converted into irregular veins of calcite. But calcite is not the only mineral found in these cavern deposits; for barite and fluorite and various lead and zinc ores, especially the sulphides and carbonates of these metals, have also been leached out of the surrounding limestone and concentrated in the caverns. The celebrated lead mines of the Mississippi Valley are of this character. The forms of these cavern-deposits vary almost indefinitely, and are
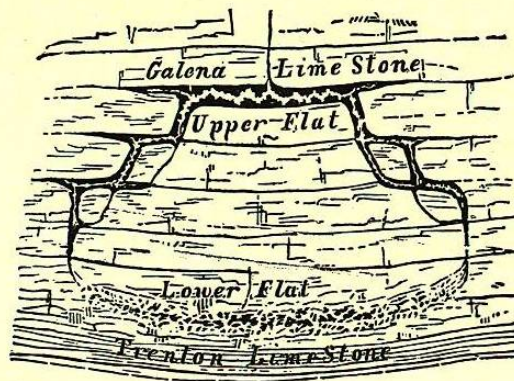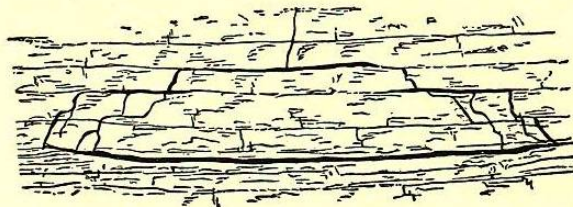

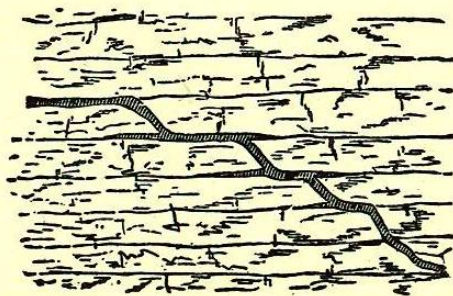Ideal section of flats and pitches.
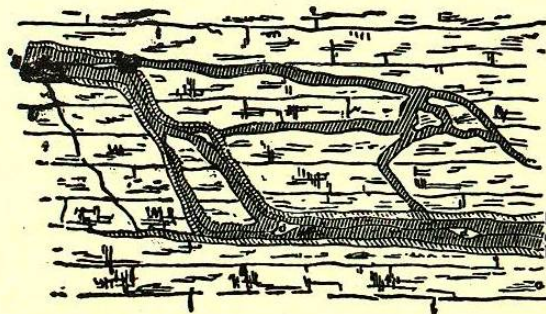
Section showing branching and banded structure of vein in the Linden Mine, Wisconsin.
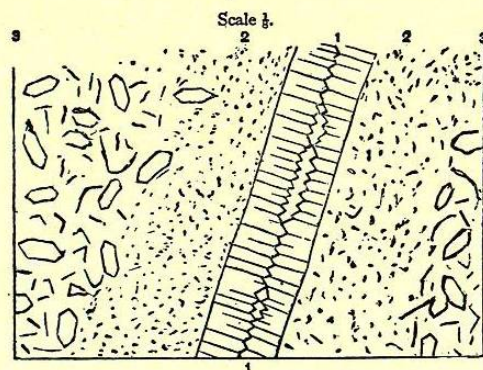
General section of the Penitentiary Range, Wis., showing the relative unimportance of the pitches as compared with the flats.
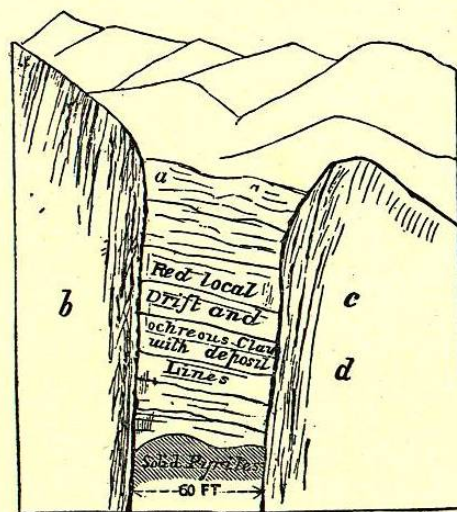

Section of Mill's Lode, Wisconsin, showing the relations of pitches and flats.

Enlarged section of a tin vein in granite, Cornwall, England.

Section of pyrite deposit, Huelva, Spain.