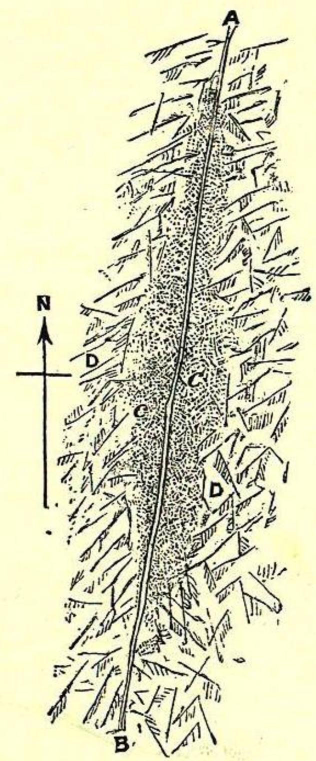


Plan of tin lode at East Wheal Lovell Mine, Cornwall, England.
AB, Leader; CC, Granite impregnated with tin ore; DD, Granite.

often highly irregular. The principal types are known as *gash-veins*, *flats* and *sheets*, *chambers*, and *pockets*.

Where joints and other cracks have opened slightly in different directions and become filled with infiltrated ores, we have what the German miners call a *stockwerk*, — an irregular network of small and interlacing veins. The small veinlets of calcite in slate from Vermont (**24, 26**) may be regarded as forming miniature stockworks.

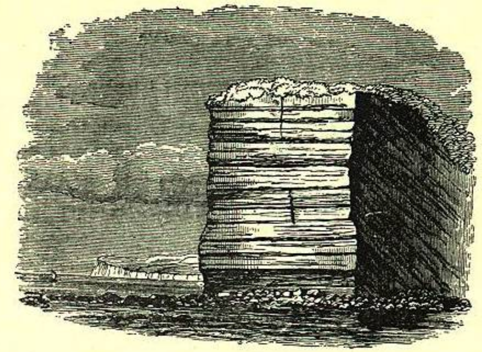
An *impregnation* is an irregular segregation of metalliferous minerals in the body of some eruptive or massive rock, usually along a joint-crack or a fault-plane. Its outlines are not sharply defined, but it shades off gradually into the enclosing rock. We must consider that the crack or fissure affords a channel for the passage of mineral waters and that the dissolved minerals, instead of simply forming a narrow vein in the crack, impregnate the solid rock on either side, the substance of the rock being often to a large extent or wholly dissolved and replaced during the process.

This process of substitution or metasomatosis is now regarded as of vast importance, many of the principal and most valuable ore deposits requiring this explanation. The specimen of slate from Quincy (**17**), which has been bleached and perhaps otherwise altered along two intersecting joint cracks, is not properly an impregnation, since it is probable there has been simply a leaching out of material without any important addition; but it serves to illustrate the general idea of the alteration of the rock along dynamic cracks or planes of weakness.

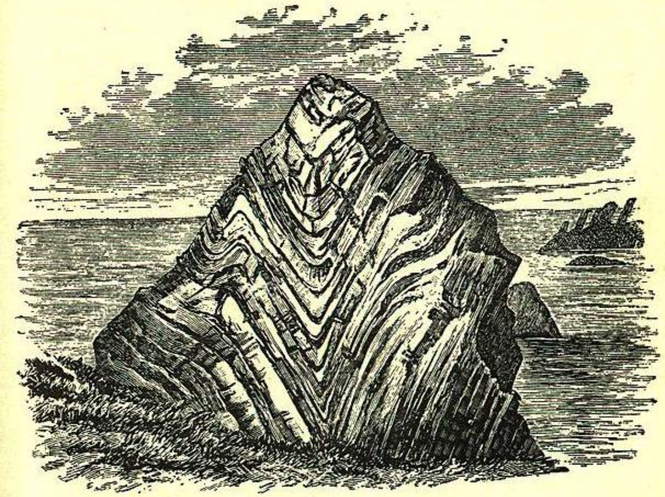
Fahlbands are similar ill-defined deposits or segregations along the bedding-planes of stratified rocks. The pyritiferous gneiss from Rowe (**18**) is a general illustration. The pyrite is quite certainly not an original constituent of the gneiss, and yet it does not form distinct veins or veinlets; but it is disseminated through the rock parallel with the bedding—a stratified impregnation, or fahlband. An impregnation, vein, or other form of ore-body occurring along the contact between two dissimilar rocks is called a *contact deposit*. These are usually found between formations of different geological ages, and especially between eruptive and sedimentary rocks.

SUBSEQUENT STRUCTURES PRODUCED BY SUBTERRANEAN AGENCIES.

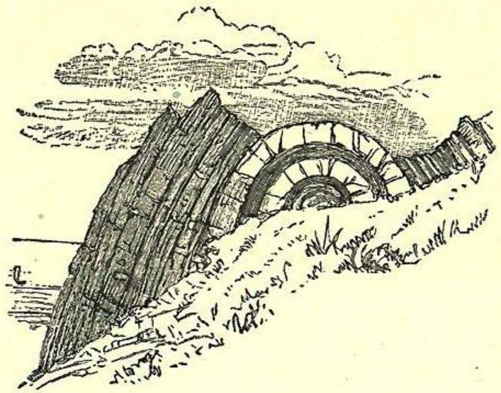
The subterranean forces concerned in the formation of rocks are chiefly various manifestations of that enormous tangential pressure developed in the earth's crust, partly by the cooling and shrinking of its interior, but largely, it is probable, by the diminution of the velocity of the earth's rotation by tidal friction, and the consequent diminution of the oblateness of its form. It is well known that the centrifugal force arising from the earth's rotation is sufficient to change the otherwise spherical form of the earth to an oblate spheroid, with a difference of twenty-six miles between the equatorial and polar diameters. It is also well known that while the earth turns from west to east on its axis, the tidal wave moves around the globe from east to west, thus acting like a powerful friction-brake to stop the earth's rotation. Our day is consequently lengthening, and the earth's form as gradually approaching the perfect sphere. This means a very decided shortening and consequent crumpling of the



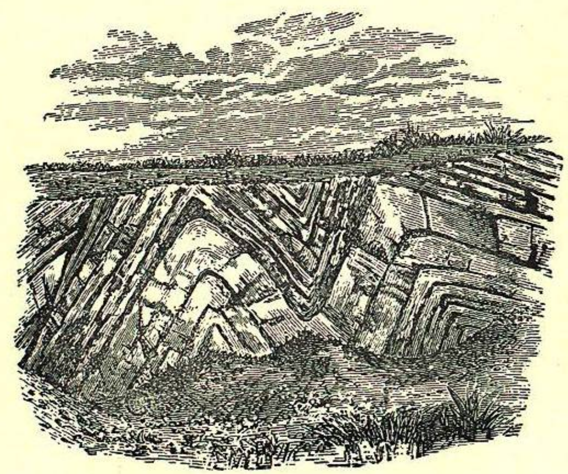
Inclined strata appearing horizontal when exposed at right angles to the dip.



Synclinal fold near Banff, Scotland.



Anticlinal fold near St. Abb's Head, Scotland.



Section showing two anticlines and a syncline. (Geikie.)

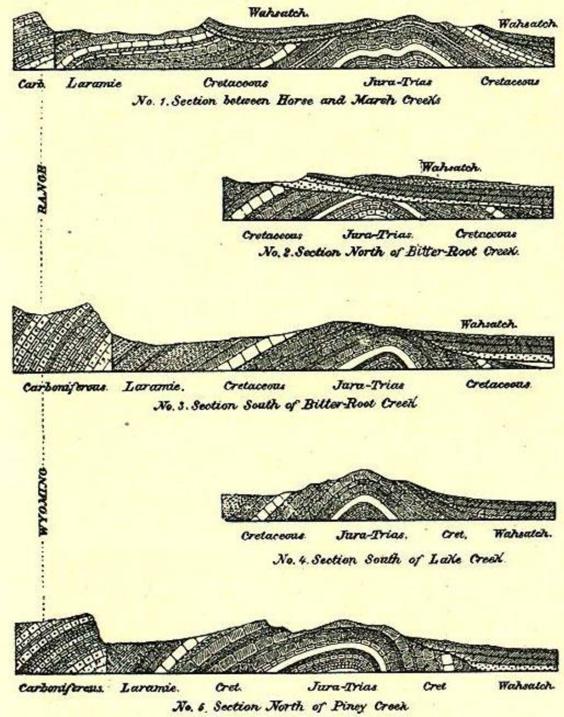
equatorial circumference, and is equivalent to a marked shrinkage of the earth's interior, so far as the equatorial regions are concerned.

The most important and direct result of the horizontal thrust, whether due to cooling or tidal friction, is the corrugation or wrinkling of the crust; and the earth-wrinkles are of three orders of magnitude: continents, mountain-ranges, and rock-folds or arches.

Continents and ocean-basins, although the most important and permanent structural features of the earth's crust, are quite beyond the scope of such a collection as this, except as their principal relief features and their general relations to the earth's crust have been exhibited in the Introductory Collection in the Vestibule. The forms and distribution of mountain-ranges might be dismissed in the same way; but, unlike continents, the structure of mountains, upon which their reliefs mainly depend, is quite fully exposed to our observation, and is one of the most important fields for the student of structural geology. Mountains, however, as previously explained, combine nearly all the kinds of structure produced by the subterranean agencies, and their consideration, therefore, belongs at the end rather than at the beginning of this section. The agency of the horizontal compression of the earth's crust in folding, wrinkling, deforming, and breaking the strata has been explained on page 30 and illustrated by suitable models and specimens; and in the printed explanations of the photographs (**4**) which form the first illustration in this section (9) the main points are stated again. But our chief purpose now is simply to study in greater detail the various effects thus produced.

Inclined or Folded Strata.—Normally, strata are horizontal, and dikes and veins are vertical or nearly so. Hence the stratified rocks are more exposed to the crumpling action of the tangential pressure in the earth's crust than the eruptive and vein rocks; and it is for this reason, and partly because the stratified rocks are vastly more abundant than the other kinds, that the effects of the corrugation of the crust are studied chiefly in the former. But it should be understood that folded dikes and veins are not uncommon.

That the stratified rocks have, in many instances, suffered great disturbance subsequent to their deposition, is very evident; for, while the strata must have been originally approximately plane and horizontal, they are now often curved, or sharply bent and contorted, and highly inclined or even vertical. All inclined beds or strata are portions of great folds or arches. Thus we may feel sure when we see a stratum, as in the model (**5**), sloping downward into the ground, that its inclination or dip does not continue at the same angle, but that at some moderate depth it gradually changes and the bed rises to the surface again, as is so clearly shown in the printed explanation and section accompanying the model. Similarly, if we look in the opposite direction and think of the bed as sloping upward—we know that the surface of the ground is being constantly lowered by erosion, and consequently that the inclined stratum formerly extended higher than it does now, but not indefinitely higher; for, in imagination, we see it curving and descending to the level of the present surface again. Hence it forms, at the same time, part of one side of a great concave arch and of a great convex arch, just as every inclined surface on the ground indicates both a hill and a valley. And guided by this principle we can often reconstruct with



Parallel sections from Wyoming Range eastward across Meridian Fold to Green River Basin, showing: the varying character of the fold; the unconformity between the Wahsatch and the older formations; and the fault between the Carboniferous and the newer formations.

much probability folds that have been more or less completely swept away by erosion, or that are buried beyond our sight in the earth's crust.

The arches of the strata are rarely distinctly indicated in the topography, but must be studied where the ground has been partly dissected, as in cliffs, gorges, quarries, etc. They are also, as a rule, far more irregular and complex than they are usually conceived or represented. The wrinkles of our clothing are often better illustrations of rock-folds than the models and diagrams used for that purpose. This is sufficiently obvious when we glance at the specimens, or reflect that the earth's crust is exceedingly heterogeneous in composition and structure, and must, therefore, yield unequally to the unequal strains imposed upon it.

The natural illustrations begin with two comparatively simple folds or bends of the strata (**21–22**). The first one is a complete fold, while the second shows only a single layer of rock, an outline or skeleton fold. In their present positions they are typical convex arches or *anticlines*, but if inverted they would be equally good concave arches or *synclines;* and may thus be used to illustrate these two principal types of folds.

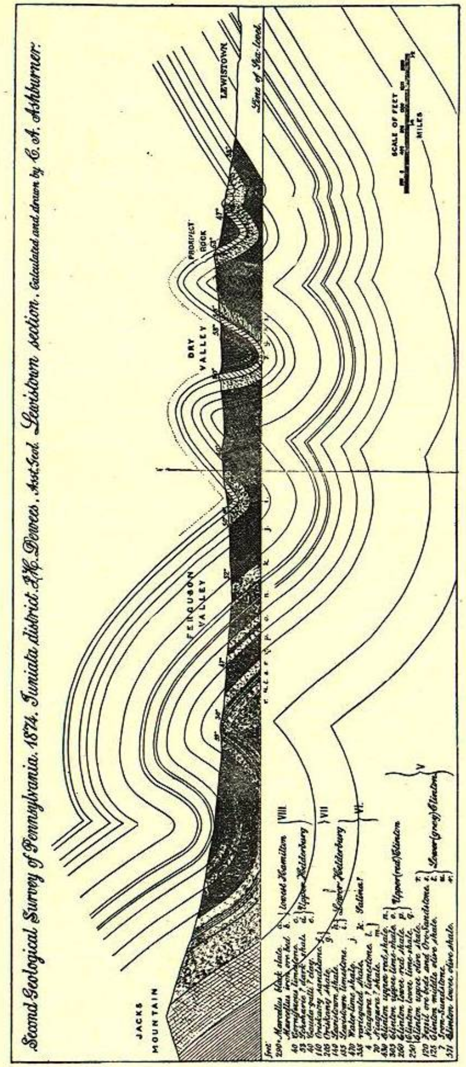
The imaginary line passing longitudinally through a fold, about which the strata appear to be bent, is the axis; and the plane lying midway between the two sides of a fold and including the axis is the axial-plane. In the anticline (**21–22**) the arch is convex upward and the beds slope downwards or dip on either side away from the axis; while in the syncline (**23**) the arch is concave upward and the beds dip toward the axis. These two types of folds are commonly, but not always, correlative. like hill and valley.

Rock-folds are of all sizes, from almost microscopic wrinkles to great arches miles in length and breadth and thousands of feet in hight. The smaller folds, or such as may be observed in hand-specimens and even in considerable blocks of stone, are commonly called contortions; and it is interesting to notice that they are, in nearly everything except size, precisely like the large folds, so that they answer admirably as geological models and are our main reliance in this part of the illustration, every one of the natural specimens showing more or less typical contortions. Large folds, however, are almost necessarily curves, while contortions, as the specimens show, are frequently angular.

The normal relation of the wrinkles or contortions to the larger folds is very clearly illustrated by the slate from Newton Centre on the second shelf (**24**). The contortions, it will be observed, are not uniformly distributed over the main fold; and it is obvious on reflection that when the rocks are folded they must be in a state of tension on the convex side of the arch, and in a state of compression on the concave side. Hence the syncline is evidently the normal position for the minor wrinkles, and they are rarely observed elsewhere.

Contortions are also most commonly found in thin-bedded, flexible rocks, such as shales and schists, as most of the specimens show; and when we find them in hard, rigid rocks, like gneiss (**41–43**) and quartzite (**21**), it must mean either that the structure was developed with extreme slowness, or that the rock was more flexible then and possibly plastic.

These minor wrinkles or contortions illustrate not only



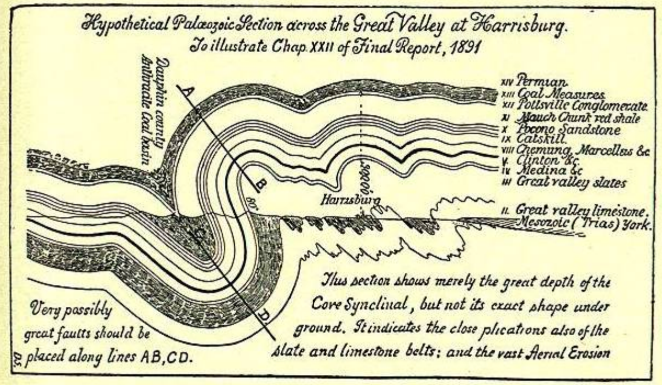
Section across the Juniata district of Pennsylvania, showing the character of the Appalachian folds and how by reconstructing the folds extensive erosion can be proved over certain areas.

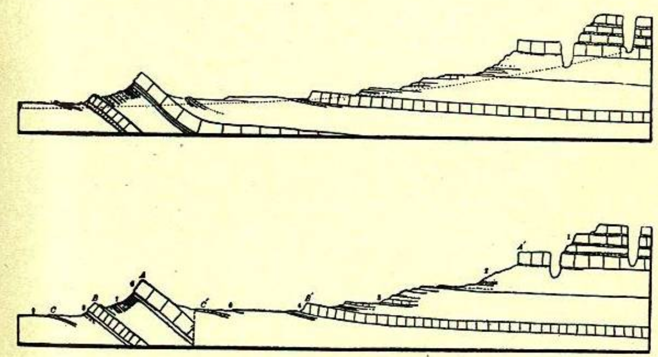
the principal types of large folds, but also the normal irregularities of folds, showing, among other things, how folds die out (**6**) and how a single fold may divide into two folds (**25**) or *vice versa*.

The monoclinal folds, or those that slope in only one direction, the one-sided arches, are seen in the small specimens (**1–3**) from local ledges, on the upper shelf; and the large specimen (**61**) in the next section (10) may be regarded as an abrupt and somewhat wrinkled monocline. This type of flexure is evidently related to, and frequently passes into, faults; and it is of great structural importance in the High Plateau region of New Mexico, Arizona, and southern Utah, as may be seen in the relief maps of the Henry Mountains in the west window.

Anticlines and synclines are *symmetrical* when the dip or slope of the strata is the same on both sides and the axial plane is vertical. The great majority of folds, however, as the specimens show, are not only generally irregular, but have at almost all points unsymmetrical cross-sections, the opposite slopes being unequal and the axial plane inclined to the vertical. This means that the compressing or plicating force has been greater from one side than from the other. It must, in the case of anticlines, have acted with the greatest intensity on the side of the gentler slope. When the steep slope approaches the vertical, this tendency is almost unresisted, and when it passes the vertical, gravitation must assist in overturning the fold (**25**). Such highly unsymmetrical folds, including all cases where the two sides of the fold slope in the same direction, are described as *overturned* or *inverted*, although the latter term is not strictly applicable to the entire fold, but only to the strata composing the under or lee side of it, as shown by one of the folds in the drawing (**1**, section 10), where the strata on either side are numbered in the order of their deposition. On the under side of the anticline the older strata are seen lying conformably upon the newer. This inversion is one of the most important features of folded strata; and it has led to many mistakes in determining their order of succession. In the great mountain-chains, especially, it is exhibited on the grandest scale, great groups of strata being folded over and over each other as we might fold carpets (**2**).

An inverted stratum is like a flattened S or Z, and may be pierced by a vertical shaft three times, as has actually happened in some coal mines. Folds are *open* when the sides are not parallel, and *closed* when they are parallel, the former being represented by a half-open, and the latter by a closed, book. Closed folds, commonly called isoclines, are usually inverted, and when the tops have been removed by erosion (**3**), the repetition of the strata may escape detection, and the thickness of the section be, in consequence, greatly overestimated. Thus, a geologist traversing the section shown in the drawing would see thirty-two strata, all inclined to the left at the same angle, those on the right apparently passing below those on the left, and all forming part of one great fold. The repetition of the strata in reverse order, as indicated by the numbers, and the structure below the surface, show, however, that the section really consists of only four beds involved in a series of four closed folds,





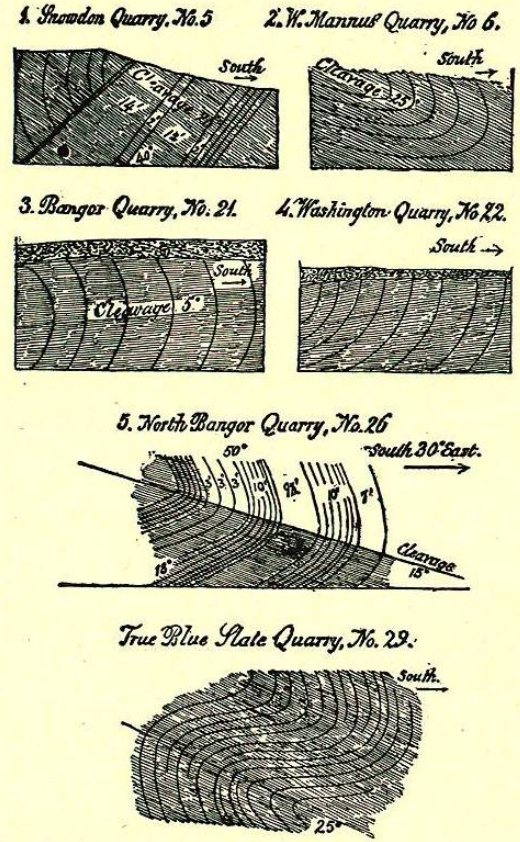
Section on the San Juan River, Colorado, showing how an apparent duplication of the strata may be explained by a fault.

the true thickness of the beds in this section being only one eighth as great as the apparent thickness.

Cleavage Structure.—This important structure is now known to be, like rock-folds, a direct result of the great horizontal pressure in the earth's crust. It is entirely distinct in its nature and origin from crystalline cleavage, and may properly be called lithologic cleavage. It is also essentially unlike stratification and joint-structure. It agrees with stratification in dividing the rock into thin parallel layers, but the cleavage-planes are normally vertical instead of horizontal. And the cleavage-planes differ from joints in running in only one direction, dividing the rock into layers; while joints, as we shall see, traverse the same mass of rock in various directions, dividing it into blocks.

The principal characteristics of lithologic cleavage are illustrated by the specimens. These show, first, that it is limited as a rule to the soft, fine-grained rocks, having its best development in the slates, as witness the roofing slates (**41–42**), school slates, slate black-boards, etc.; for slate owes its adaptation to these and other uses chiefly to this wonderful structure, commonly called slaty cleavage, which causes it to split or cleave with remarkable regularity into sheets of any desired thinness. An imperfect cleavage structure is sometimes observed in coarser rocks, such as sandstone and conglomerate (**21**), but these are invariably found on examination to be of a soft and slaty character. The practical limitation of the slaty cleavage to the slates is especially obvious where they are interstratified with coarser and harder rocks. Thus the specimen from Nantasket (**23**), which represents a bowlder lying on the shore at the southern end of the beach, shows two layers of gray sandstone separating three layers of dark bluish gray slate. The slate layers exhibit a very distinct cleavage nearly at right angles to the stratification; but the cleavage planes end abruptly in every instance at the junction with the sandstone and cannot be traced into the latter rock. The large specimen on the third shelf (**44**) embraces two distinct layers, — a layer of soft, pure slate with perfect cleavage, with a broader layer in front of it of a coarser, sandy slate in which the cleavage is quite imperfect and in a somewhat different direction. Where the alternating layers of coarse and fine slate are much thinner, the frequently changing character of the cleavage produces the so-called curly slate (**22**). The best illustration of all, as regards the relations of cleavage-structure to the character of the rocks, is afforded by the other large specimen on the third shelf (**43**). This is chiefly a well-cleaved slate, the cleavage-planes being parallel to the oblique under surface of the specimen. Toward the left end, two oblique lines of stratification are very plainly marked, and parallel with these, through the middle of the specimen, runs a very distinct layer nearly two inches thick of impure limestone. The cleavage does not extend through the limestone; but it is obvious at the first glance that the force which developed the cleavage in the slate has simply broken, distorted, and faulted the more rigid and unyielding limestone.

The specimens show, second, and with equal clearness, that the cleavage-planes are usually highly inclined and transverse to the bedding or true stratification. This is



Sections in the slate quarries of Bangor, Pa., showing the relations of the cleavage to the foldings of the strata.