structural basins bounded by fault scarps (202). All topographic forms which have been derived through the extensive erosion and consequent extensive modification of original topographic features due to faulting are subsequent. Such are fault-line scarps (274, F), fault-line gaps (291, E), and horsts, grabens, and basins, bounded by fault-line scarps (224). Here also may be mentioned alignment of solution-made sink-holes (Art 290).

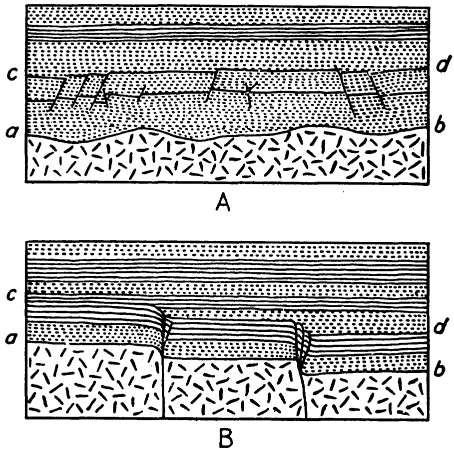

FIG. 229. Sections to illustrate the difference between faults which were limited to superficial sediments (A) and those which, although appearing in the superficial sediments, had their origin in the underlying bedrock (B). *ab*, line of unconformity between ancient rock foundation (dash pattern) and sediments which were unconsolidated at the time when they were dislocated. *cd*, original land surface at time of faulting. In both cases this surface was later buried under younger sediments.

224. Topographic expression of horsts, grabens, and basins. Horsts, grabens, and basins are included in the list just given because, if they are comparatively small, or if their characters are very pronounced, they are recognizable as topographic forms; but ordinarily they are so large and their surfaces are so varied in relief that their study can be accomplished only by extensive field investigations. Consequently, although the scarps, valleys, and other land forms are described in Chap. 11, horsts, grabens, and basins will receive consideration here.

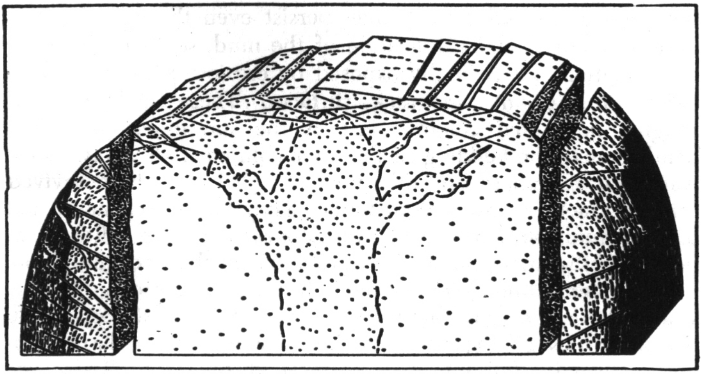

FIG. 237. Association of flat-lying normal faults with marginal fissures and thrusts. Along steep contacts (left and right), marginal fissures prevail. They lengthen the massif upward and outward. The flat-lying normal faults (center) distend the intrusive horizontally and seem to develop especially near subhorizontal contacts. In some instances, the expansion along these fracture systems seems to be caused by continuous intrusion of magma into the core of a massif. (*After Robert Balk, Bibliog.*, 1937, *p.* 107. *See caption for Fig.* 235.)

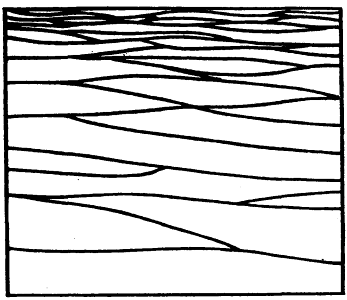

FIG. 238. Vertical section of sheeted granite. The joints or sheets inclose roughly lenticular slabs of the rock between them.

it and stratification. Even granites and other igneous rocks that are well sheeted may look very much like strata from a distance.

237. Columnar and transverse jointing not related to igneous eruption. Sun cracks are an example of original or contemporaneous hexagonal columnar jointing (**65**). The tendency to the mica predominate. These lenses range from less than an inch to many feet in length. A *gneiss* is a metamorphic rock in which a banded distribution of its constituents is more conspicuous than a parallel orientation of the individual grains. Many gneisses contain feldspar, quartz, and mica, so that they

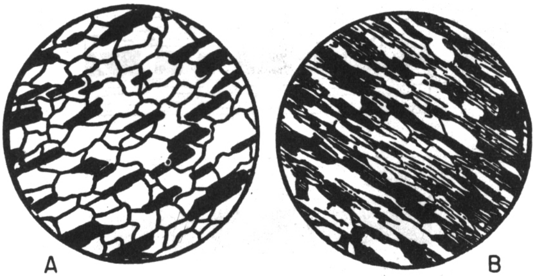

FIG. 247. Microscopic sections of cleavage structure developed through rock flowage. In A the biotite (black) is arranged with its laths all parallel and the quartz grains (white) have a slight tendency to be elongate parallel to the mica. In B there are three different minerals, all of which are oriented in parallel position. Which rock would probably have the better cleavage? (*B is after Blackwelder and Barrows.*)

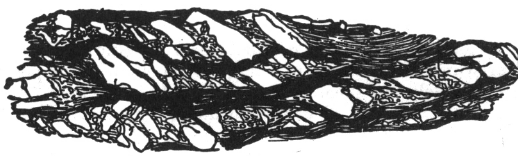

FIG. 248. Microscopic section of "sliced" feldspars (white) in mica schist. (*After C. K. Leith.*)

look like granitic rocks, especially if their banding is not pronounced (**253**). In gneisses, foliation is not so well developed as in schists.

Flow cleavage is produced, *i.e.*, rock flowage is accomplished, by granulation, recrystallization, and rotation, thus: (1) Brittle minerals are crushed and the aggregates of minute fragments are flattened in planes at right angles to the maximum stress (Figs. 246, 248). This is *cataclastic structure.* (2) From the old conat an acute angle is probably in the limb of a fold. Of great importance in this connection are the two rules which have been stated before with reference to parallel folding, namely: (1) the cleavage planes lean in the direction of differential movement between adjacent beds (Fig. 255); and (2) this differential motion is such that any bed slips over the next underlying bed upward toward anticlinal axes (178). By the application of these rules the geologist can tell on which limb of a fold an outcrop is situated, and which are the upper and lower beds in cleaved vertical strata. Thus, in Fig. 257, at the contact *a–b* the cleavage cracks in bed 2 lean toward *a* and so indicate that 1 moved over in this direction. Similarly, 3 slipped along 2 toward *c*. This section, then, must be a part of a limb between an anticline on the right and a syncline on the left. Successively younger beds are crossed up to the axial region of the syncline in passing from right to left across the outcrops (cf. 185). "Cleavage in a slate area may strike east and west and dip south at an angle of 45°. The inference is that here are similar composite folds with east-west trend and axial planes dipping to south; further, that the structure was developed by the relatively northward movement of some overlying competent rocks which have been removed; finally this inferred major control suggests a major anticline to the north."[11]

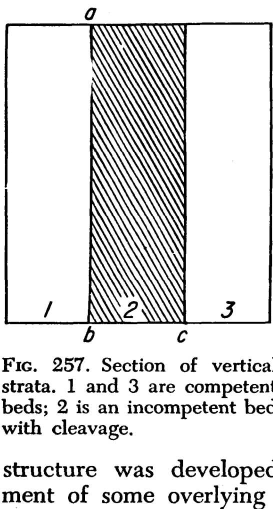

FIG. 257. Section of vertical strata. 1 and 3 are competent beds; 2 is an incompetent bed with cleavage.

250. Distortion of original structures, fossils, pebbles, etc. Of the two kinds of metamorphism, static and dynamic, the former is least apt to blur and destroy original structures in a rock. Pebbles, fossils, and such lithologic features as ripple-mark and cross-bedding are little, if at all, altered in shape, except in so far as they are flattened by compression of the rock as a whole (Fig. 258). Indeed, the lithologic structures may be made more conspicuous by the growth of new minerals in layers or lines such

[11] Bibliog., Leith, C. K., 1913, p. 132.

gangue the ore minerals may be disseminated as fine particles, or distributed in threads, or segregated in masses, or otherwise arranged. Although ore minerals are sometimes native, as gold, copper, platinum, and mercury, they are usually sulphides, oxides, carbonates, sulphates, chlorides, or other compounds.

261. Size of vein deposits. In thickness veins may range from a fraction of an inch to many yards, and in length they may range from a fraction of an inch to several miles. Many have been followed downward to depths of 3,000 or 4,000 ft.

262. General field relations of veins. The attitude of a vein is referred to in the same terms as that of a fault, a dike, or a bed. Strike, dip, and hade are used with the same significance as defined in Art. **199**. A majority of veins have dips steeper than 50°. When a vein is inclined the wall above it is the *hanging wall* and that below is the *footwall* (Fig. 263).

The geologic age of a mineral deposit is determined by correlation with fossiliferous strata or with other rocks whose age has been established.

With reference to their relations to the land surface, veins may be more resistant or less resistant to the influences of weathering than their wall rocks. If stronger, they project as ridges. When small and numerous, they give to an outcrop a ribbed surface or a honeycombed appearance according as they are in parallel or intersecting sets. If they are less resistant than their country rock, they weather down below the general level and become covered with their own residual débris (gossan, etc.).

The trends of outcropping veins conform to the rules which have been set forth in Art. **193** for strata.

263. Discrimination between open-space deposits and replacement deposits. No infallible rule can be laid down for ready discrimination between open-space and replacement deposits. There is generally some alteration in the walls of open-space deposits and, on the other hand, replacement bodies may be situated along fissures which conducted the mineralizing solutions. Every gradation exists between the two classes. Nevertheless there are certain features which are especially characteristic of one group or the other, and these, when properly interpreted, may be of considerable assistance as distinguishing marks. (1) Usually, not always, replacement deposits have rather indistinct or blended contacts and open-space deposits have sharply defined *boundaries*. (2) Open-space bodies ordinarily have a banded or