12

Features of Deformed Rocks

12-1. Early Formed Deformational Features

The principal subjects of this chapter are features formed in solid rocks by tectonic processes—folding, faulting, and more evenly distributed strains. Melanges are included because of their importance in tectonically active regions, even though many melanges are of sedimentary origin (Section 12-7). Melanges, in fact, point to the more general problem addressed in this first section: how to recognize tectonic deformation of unconsolidated sediments.

Unconsolidated and partly consolidated muds generally have porosities between 40% and 80% and may thus undergo strains by loss of pore water alone (Fig. 12-1A and B). At large strains (Fig. 12-1C), flaky grains in mudstone may be rotated sufficiently to produce anew planar fabric and thereby a slaty cleavage (Williams and others, 1969; Clark, 1970). The cleavage has most of the attributes described in Section 12-4, but its soft-sediment origin can be recognized where liquefied sand has intruded along the cleavage planes as well as across them (Fig. 12-2A) (Powell, 1972). The parallelism must be exact, however, because large postconsolidation strains will typically rotate sandstone dikes toward the plane of slaty cleavage in mudstone (Boulter, 1974). Additional indications of tectonic deformation of soft sediments are faults that break semiconsolidated layers but not unconsolidated ones (Fig. 12-2B), and beds of sand, silt, and clay that have become mixed to a sandy mudstone in shear zones that have indistinct or irregular margins (Fig. 12-2C).

Nontectonic deformational structures in soft sediments are described in

![Fig. 12-1. Tectonic shortening of unconsolidated mud containing a rigid body (as an early formed concretion), a stained but otherwise identical mud body, and a bed of sand. A, initial state, porosity = 60%; B, after 25% shortening; and C, after 50% shortening and 10% vertical extension. Vertical lines represent cleavage.](image-url)
Section 9-3, and primary deformational structures of igneous rocks are described in Chapters 13 and 14. The forms and associations of these structures should be reviewed during mapping, because they can easily be mistaken for tectonic features.

12-2. Determining Directions and Amounts of Strain

The directions in which a rock has been deformed (strained) may be indicated by the shapes and orientations of grains or structures whose original shapes are known, such as oolites, sand grains, or fossils. The amounts of strain can be approximated by measuring the dimensions of the strained forms and comparing them with the original dimensions. The shapes of some deformed grains and structures indicate, further, the kind of strain that took place. *Flattening* is expressed by equidimensional grains and structures that have been pressed into symmetrical plates or disks (Fig. 12-3A). *Extension* is indicated by grains elongated and constricted so as to become prisms or rodlike ellipsoids with equidimensional cross sections (Fig. 12-3B). Measurements of the lengths and widths of these bodies give a
Fig. 12-4. Cubic and spherical bodies deformed by simple shear (A), by pure shear (B), and by a combination of simple and pure shear (C), giving new forms (the parallelograms and ellipses) of similar shape and orientation.

The general kind of strain in both cases just described is called pure shear, a deformation that has taken place symmetrically around an axis of flattening or elongation, without rotation of the strained body. In simple shear, an axis of principal strain rotates progressively with increasing amounts of shear, and the grain or structure changes shape much as though it were a stack of very thin sheets displaced laterally (Fig. 12-3C). The height of the skewed cube (the axis perpendicular to the shear plane) remains unchanged, as does the axis lying parallel to the shear plane and perpendicular to the direction of shear. The sphere, for example, becomes a triaxial ellipsoid in which the axis roughly perpendicular to the page is the same as a diameter of the original sphere.

Fig. 12-5. Changes of shape and fabric in a granite body with inclusions, where simple shear and accessory flattening are concentrated in a tabular zone. The zone is considered a ductile fault when the displacement of the two walls is more than 5 to 10 times the thickness of the zone (Wise and others, 1984.)
Simple shear is an important kind of geological strain, such as in fault zones or near the contacts of intrusions. In deformed solid rocks, however, simple shear is not always distinguishable from pure shear, at least not on the basis of the shapes of grains or structures alone. The three ellipsoidal bodies in Fig. 12-4, for example, are similar in shape and orientation.

In the field, one can seek additional evidence for kinds of strain, and it may be helpful at the outset to assume that any distinct foliation includes at least one principal axis of the strain ellipsoid, and that a distinct lineation in this foliation is parallel to one of the axes. Additional features and measurements may then be referred to these axes to determine the kinds of strain that have contributed to the total strain of the rocks. Where simple shear has been dominant, rocks tend to show different amounts of strain from one part of a foliated body to another, giving rise to variation in the shapes and orientations of deformed features (Fig. 12-5). Also suggestive of simple shear are phacoidal bodies of rock separated by fine-grained or schistose sheets (Fig. 12-6A) or by faults. Veins, color bands, or cross-beds oriented at a large angle to the direction of simple shear may be cast into folded forms and, if so, the dimension parallel to the direction of shear remains unchanged from one part of a fold to another (Fig. 12-6B). In metamorphic rocks, porphyroblasts may show systematically rotated inclusions because the crystals rotated as they grew (Fig. 15-2B), and undeformed porphyroblasts in foliated rocks may have skewed deposits of quartz or carbonates (Fig. 12-6C). Patterns of cleavage and gash fractures may indicate simple shear (Fig. 12-6D).

**Fig. 12-6.** Suggestions of simple shear. *A.* Section through granular rock cut into lenticular prisms by thin zones of schistose or slaty rock. *B.* Stages in the deformation of a vein by simple shear parallel to the short lines, which are all of the same length. *C.* Deposits of quartz in “strain shadows” next to crystal that apparently rotated due to simple shear during deformation. *D.* Orientations of cleavage (thin lines) and of veins in gash (extension) fractures in clayey limestone affected by simple shear in a tabular zone.