14

Field Studies of Plutons ■

14-1. Rock Units, Ages, and Depth Relations

The term *pluton* is used here in a general sense, implying only a subjacent body large enough to map to scale, typically intrusive but not necessarily so. Plutons may occur singly but typically are in groups, commonly forming linear chains of separate plutons or belts of overlapping plutons. The great batholiths that evidently formed beneath volcanic arcs, such as the Coastal Batholith of the Peruvian Andes, are composed of hundreds of plutons (Pitcher, 1978).

A pluton may consist of one rock unit or more than one, and nearby plutons may consist of the same unit(s) or of different ones. The most crucial step in mapping plutons is coming to know these rock units as exactly as possible. Ideally, one should be able to recognize a specific unit whether it recurs in another pluton tens of kilometers away or as a few inclusions in a dike nearby. Rock units must therefore be based on all primary features possible: (1) proportions among specific varieties of minerals; (2) all aspects of texture (Sections 4-4 and 14-2); and (3) kinds, shapes, and sizes of inclusions, layers, and schlieren (Sections 14-3,14-4, and 14-5). Associated dikes, pipes, veins, and alterations may be helpful if they reflect the unit's original magmatic constitution; for example, its content of volatile substances or its tendency to segregate late-stage melts (Sections 14-6 and 14-7).

These fundamental mapping units have commonly been called *plutonic units* and are equivalent to formations in sedimentary rocks or to the lithodemes of the stratigraphic code (Section 5-3). Lesser units might be local textural or altered variants that are modifications of a given plutonic unit. A plutonic unit might thus have a *foliated facies* near certain contacts or a local *sericitic zone* due to superimposed alteration.

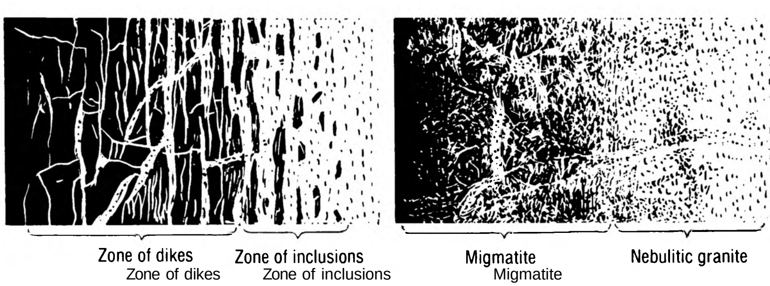
Plutonic units may be assembled into *plutonic suites* on the basis of features or relations indicating a close genetic relation. Chief among these indicators are geographic association, similar age, and minerals and mineral reactions indicating chemical affinity. A close genetic relation can be checked in the laboratory by determinations of numerical ages, chemical compositions, and isotopic compositions.

Plutonic suites are important because they give a basis for judging the source and history of magmatic sequences. For example, Shaw and Flood (1981) were able to classify a series of plutonic suites into *S-type suites* (thought to be derived mainly by melting of metasedimentary rocks) and *I-type suites* (derived from igneous or metaigneous rocks). This particular distinction was based largely on isotopic compositions of Sr, 0, and S, but S-type suites were also indicated by minerals reflecting a high A1 content (presence of cordierite, Al-rich garnet, or an Al_2SiO_5 polymorph), and I-type suites by minerals indicating relatively low A1 content (hornblende with or without augite). Pitcher (1984) has summarized the characteristics and geologic environments of these two suites and two others, and has discussed pertinent literature.

Contacts between plutons and country rocks are usually distinct and readily mapped. Sharp contacts may be irregular due to blocky reentrants, cuspate forms, or folds, and these features should be mapped to scale, if possible, or recorded by suitable notes or by some design on the map. Where the contact is a broad gradation, the line is generally placed at the center of the gradation or where the plutonic rock forms a more or less continuous matrix around inclusions of country rock. In some cases two adjoining zones of mixed rocks can be mapped (Fig. 14-1). Pluton margins are likely to be broadly schistose or mylonitic in plutons emplaced diapirically when the body was more than 70% crystallized, and the contact may lie within this broad zone of ductile shear (Soula, 1982).

Dikes near the contact generally are of great value in interpreting a pluton's evolution. They may belong to one of these age groups: (1) dikes associated with the pluton but cut by it (Fig. 14-2*A);* these dikes may record the composition of the first magma emplaced at the observed level; (2) apophyses connected to the pluton, which, if porphyroaphanitic, will indicate the proportion of crystals to melt at this margin; (3) dikes emplaced when the pluton was still mobile and probably contained some melt (Fig. 14-25); (4) dikes without chilled margins, emplaced in the pluton when it was still hot; and (5) dikes with chilled margins, emplaced in the pluton after it had cooled.

Contacts between rock units within plutons may be obscure where two rocks are almost identical or where they grade to one another. Such contacts may be marked by: (1) small differences in color and texture; (2) inclusions, schlieren, or layers in the younger rock, commonly forming a zone parallel



Zone of dikes Zone of inclusions Migmatite

Fig. 14-1. Diked *(left)* and migmatitic gradational margins of plutons.

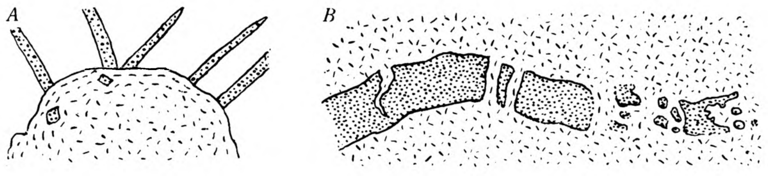


Fig. 14-2. *A*. Pluton emplaced into a radial array of somewhat older dikes. *B*. Dike broken, intruded, and partly granitized within the rock it intruded.

to the contact; (3) features in the older rock (inclusions, fabric, schlieren, layers, dikes) cut off by the younger rock; and (4) mild to moderate deformation of the grains in the older rock, which generally makes the rock darker than usual. The latter criterion must be used with caution, because magmas that are largely crystallized may develop a dark schistose or mylonitic contact facies due to ductile shear against an older rock (V. R. Todd, personal communication, 1984).

Relative ages can be determined from most of the features just listed. Where none of these features can be found, the younger unit commonly shows a broad gradation away from the contact, generally involving one or more of color, grain size, mineral content, numbers of inclusions, and abundance of schlieren (Moore, 1963, p. 43). Emplacement of the younger unit will typically remove the original marginal facies of the older, which will therefore be more uniform than the younger. Age relations are more difficult to determine where a septum of country rock lies between two intrusions; however, dikes of the younger may intrude the older, or dikes associated with the older may be cut off, deformed, or metamorphosed by the younger (Fig. 14-3).

Relative ages of emplacement are not necessarily resolved by cross-cutting relations, especially in areas where the country rocks are broadly metamorphosed. In a case described by Soula (1982), magmatic diapirs

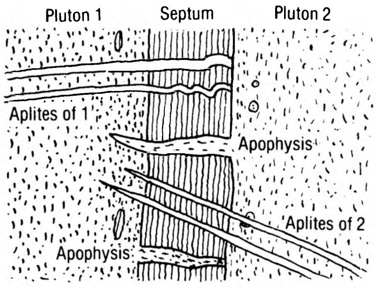


Fig. 14-3. Dikes indicating age relation between two plutons with a septum (intervening sheet of country rock).

cutting upward into nonmagmatic gneiss domes have the same emplacement age as the domes but are discordant because they were less viscous than the domes. Viscosity contrasts may affect intrusive relations in other situations. Viscosity of magma can be predicted to decrease with decreasing SiO_2 content, with increasing content of water and halogens, and with decreasing proportions of suspended crystals and inclusions.

Dating plutons is done most conveniently and least expensively by K-Ar methods (Dalrymple and Lanphere, 1969). The data obtained give cooling rather than emplacement ages, however, which may be a major problem in areas heated broadly at a later time, or in cases where a pluton is heated by a younger intrusion. Even for a single pluton, one or two K-Ar dates may suggest an erroneously simple history. U-Pb dating of zircons from the Tatoosh pluton in Washington, for example, indicated an emplacement history lasting for approximately 12 m.y. (Mattinson, 1977).

U-Pb dating of zircons, however, requires large to very large whole-rock samples and even they may not yield zircons that will give a useful age. The Rb-Sr method will give a dependable emplacement age as long as the rocks used are fresh, have all developed from one starting magma, and represent a large range of rubidium concentrations, which generally increase between the initial melt and the late residual melts of a pluton. Late potassium-rich dike rocks, such as aplites, are typically rubidium-rich; however, they need not necessarily have formed from the pluton in which they occur.

Mapping the country rocks for considerable distances around a pluton is likely to be at least as informative as studying the pluton itself. This mapping may provide the only firm evidence of mechanisms of emplacement (Fig. 14-4) (Nelson and Sylvester, 1971; Pitcher and Berger, 1972). Studies of contact metamorphism will always be of unique value (Chapter 15). The stratigraphy and detrital content of sedimentary and volcanic rocks deposited during and after a pluton's emplacement may provide the only clear evidence of uplift or subsidence of the rocks over the pluton, of connected volcanic activity, and of the date at which the pluton was unroofed by erosion (Fiske and others, 1963, pp. 59, 63).

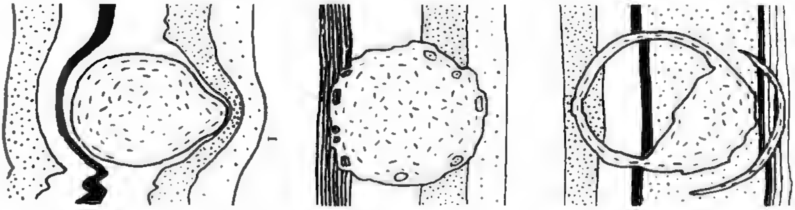


Fig. 14-4. Diagrammatic mapped relations of plutons and country rocks, indicating (from *left* to *right)* diapirism, piecemeal stoping, and cauldron (block) subsidence.