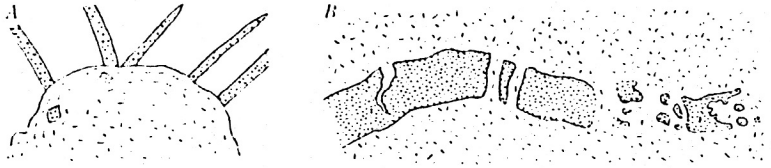

Fig. 14-2. *A*. Pluton emplaced into a radial array of somewhat older dikes. *B*. Dike broken, intruded, and partly granitized within the rock it intruded.

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 cut-

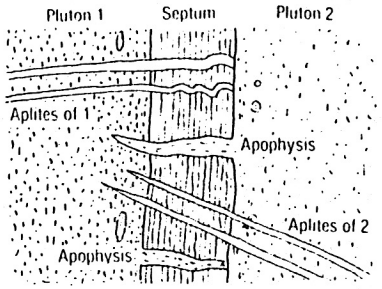

Fig. 14-3. Dikes indicating age relation between two plutons with a septum (intervening sheet of country rock).

ting 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).

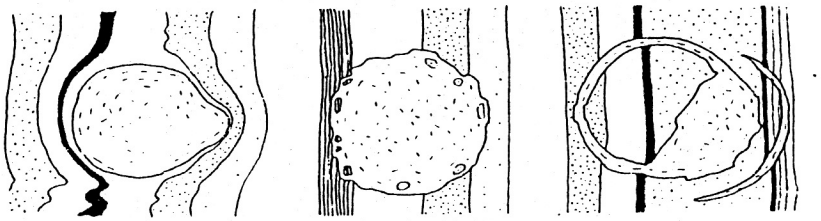

Fig. 14-4. Diagrammatic mapped relations of plutons and country rocks, indicating (from *left* to *right*) diapirism, piecemeal stoping, and cauldron (block) subsidence.