rocks in which the tectonic history is simple and interfering problems of recrystallization and preferred orientations of $c_v$ are minimal.

## Recrystallization

General. Recrystallization of a given mineral species in a polycrystalline aggregate can occur below the melting temperature by solution and redeposition and/or solid diffusion. There is a large literature on the subject, especially in metallurgy, ceramic engineering, and glass technology.(94,152-158) Of concern here is the fact that the petrofabric literature abounds with descriptions of preferred crystallographic orientations of crystals, which for textural reasons can not be explained on the basis of cataclastic or gliding flow. That is, there is no visual evidence of grain breakage or intragranular gliding. Presumably these orientations have resulted from recrystallization during deformation (the paratectonic or syntectonic recrystallization of Sander(1)), i.e., under conditions of nonhydrostatic stress. Most of them have been interpreted only kinematically by means of the symmetry argument. The same crystallographic orientations, however, might be amenable to dynamic analysis if one understood the relationships between the orientations of the recrystallized grains and the principal stresses. Significant contributions to the problem have been made through thermodynamic and experimental investigations. Initial results are encouraging and suggest the potential usefulness of these approaches.(159)

Thermodynamic Approach. The thermodynamic principles of the behavior of elastically strained solids under nonhydrostatic stress in contact with fluids were laid down by Gibbs.(160) Significant departures from the Gibbs treatment were given by Goranson,(161-163) Verhoogen,(164) and MacDonald.(165) Kamb(166) has reviewed these in detail and finds that all are essentially identical with respect to prediction of the most stable crystal orientation. Kamb(167) believes that only the Gibbs theory is valid and applies it to the simplest possible model of the recrystallization process. Recently, Kamb(168) has demonstrated experimentally the validity of the Gibbs approach and the inadequacy of all other theories so far advanced. It is instructive to compare the MacDonald and the Gibbs-Kamb approaches and the crystal orientations they predict.

MacDonald(165) assumed that the most stable orientation for a mineral would be the one for which the potential energy of the external forces plus the potential energy of strain was minimized. If the deformation is isothermal and obeys a linear elastic stress-strain law, then the most stable orientation will be the one in which the Helmholtz free energy is a maximum. This neglects any permanent strain energy, and the nature of the path from the initial to final states of the mineral, i.e., the final orientation, is supposed to be independent of the orienting mechanisms.

Brace,(169) using MacDonald's prediction, calculated the most stable orientations for calcite, high and low quartz, and ice for a uniaxial stress. His results show that the following crystallographic planes should be nearly normal to the load axis: $\{10\bar{1}1\}$ in ice and calcite, $\{10\bar{1}2\}$ in high quartz, and $\{02\bar{2}1\}$ in low quartz. Their respective $c_v$ will then tend to lie along small circles or girdles of specific half-angle about the unique stress axis (Fig. 47). Brace also examined the equilibrium orientation in a stress field of three different, nonzero, principal stresses. He found that the position of most stable orientation is a function of the confining pressure as well as the stress difference. Accordingly, different orientation patterns of grains might occur in rocks for which the stress difference was similar but the depth of burial different.

Very different results have been obtained by Kamb(167) from the Gibbs theory. He considers that the orientation of a mineral depends only on the stress deviators and is therefore independent of changes in hydrostatic pressure. When recrystallization takes place by solution and redeposition, the most stable orientation of the crystal is that which minimizes the chemical potential across the plane normal to the greatest principal pressure. Accordingly, the axis of least elastic modulus (e.g., the $c_v$ of calcite) tends to align itself parallel to the greatest principal stress axis (axes), and the axis of greatest elastic modulus (e.g., the $c_v$ of quartz) tends to become