Role of microtexture in isotopic exchange and weathering in alkali feldspars

I. Parsons
M.R. Lee
K.A. Waldron
F. David
L. Walker
Department of Geology and Geophysics, The University of Edinburgh, West Mains Road, Edinburgh, EH9 3JW, UK

R. Burgess
Isotope Geology Unit, Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow, G75 0QU, UK

W.L. Brown
CNRS-CRPG, BP 20, F-54501 Vandoeuvre-lès-Nancy Cedex, France

Character of fast diffusion paths for argon and oxygen isotopic exchange

Feldspars are often unretentive of radiogenic ^{40}Ar ($^{40}Ar^*$) and give young apparent ages using the K-Ar and $^{39}Ar/^{40}Ar$ methods. Similarly, feldspars frequently exchange oxygen isotopes to low temperatures and are the last mineral to close in multiphase assemblages. Because of their abundance and reactivity, feldspars in many crustal rocks approximate to the infinite reservoir of exchangeable oxygen implicit in the formulation of closure temperature, T_c. For both isotopic processes, T_c is often much lower than would be expected using volume diffusion coefficients determined experimentally using 'gem quality' crystals. The reasons are microtextural and are ultimately related to intracrystal phase behaviour. In nature, $^{40}Ar^*$ is lost and ^{18}O exchanged via routes that permit rapid, non-volume diffusion or involve a non-diffusional process such as solution-redeposition. Calculations of thermal history require estimates of the effective diffusion dimension (or dimensions in 'multidomain' samples) and the effective grain shape, together with knowledge of the reaction process and the time-temperature evolution of the microtextures.

Pathways for fast diffusion will be illustrated using transmission and scanning electron microscopy, and include lattice-scale dislocations, pores, and subgrain boundaries. Dislocations occur along perthite lamellae in Ab-rich ternary feldspars from syenitic rocks and granulites and in Or-rich crypto- and micro-perthites in many granites. Their development is a function of bulk composition and is a response to the need to reduce coherency strain. TEM micrographs will be presented of features in Or-rich feldspar phenocrysts from the subsolvus granite from Shap, northern England, which show that, once formed, the dislocations provide pathways into the interior of crystals which lead to dissolution and reprecipitation of feldspar far from the crystal surface. The resulting microtexture contains numerous subgrains with a network of walls and micropores between them. A similar microporous texture forms along fractures permeated by aqueous solutions; together, these features are responsible for the variable translucency of common feldspars. The textures imply abrupt decrease in effective diffusion dimension during cooling, by a factor $\geqslant 10^3$, at $T < 350°C$, leading to a reactive, easily modified, micropermeable structure. Microporous texture also develops in An-poor feldspars from hypersolvus syenites but in this compositional range dislocations do not develop as a result of coherency strain and recrystallisation is not preceeded by development of dislocations independently of fluid-crystal interactions; it may occur at $T \leqslant 450°C$.

Driving forces

Free energy changes associated with $^{18}O-^{16}O$ exchange are trivial (Giletti 1985) and a driving force for recrystallisation is required. Crystal bulk compositions usually remain constant during deuteric reactions (although not during diagenetic albitization) and there are two main driving forces for recrystallisation, collectively called 'unzipping'. Elastic strain energy stored in coherent cryptoperthites is large, $\sim 2.5-4$ $kJmol^{-1}$; reduction in free energy by this amount will occur when strain-controlled intergrowths recrystallise to coarser, largely incoherent intergrowths. A second driving force is loss of strain energy of $\sim 2-3$ $kJmol^{-1}$ in the 'tweed' orthoclase domain texture on its transformation into 'tartan' twinned microcline.

Weathering and experimental dissolution

Dislocations and microporous texture are critically important in weathering. Naturally and artificially weathered feldspar grains have extremely irregular surfaces covered by etch-pits. In highly dissolved grains the pits coalesce leading to delicate skeletal relics. Pits on the µm-scale have generally been assumed to be weathering products produced by selective dissolution around lattice-scale reactive sites. Dislocations in semicoherent microperthites commonly form linear arrays spaced at 200–700 nm. These readily etch in HF and in water and evolve into etch pits on weathered surfaces. However, the irregularity of distribution of 'etch pits' on many weathered surfaces suggests that the majority are actually enlarged original micropores, formed during cooling of the protolith. The density of original micropores is comparable to that of lattice-scale dislocations proposed in theoretical treatments of weathering (e.g. Lasaga and Blum, 1986). Estimates of surface area of alkali feldspars obtained by the BET gas adsorption method are always larger than the geometrical surface area by a 'surface roughness' (SR) factor of between 14 and 3. Measurements of SR by Atomic Force Microscopy indicate SR of only ~2 (Blum 1994), so that the enhanced surface area must be internal to the crystals. Gases used in the BET method have molecular diameters ~0.4 nm so that pores connected by subgrain boundaries and dislocations can contribute to enhanced surface area. We conclude that microtextures in alkali feldspars which develop during cooling from T < 450°C are the main reason for their reactivity both in hydrothermal fluids and during weathering and diagenesis.

References

Giletti, B.J. (1985) *Chem. Geol.*, **53**, 197–206.

Blum A.E. (1994) In *Feldspars and their reactions*, (I. Parsons ed.), NATO ASI series, C421, Kluwer Academic Publishers, Dordrecht, 595–630.

Lasaga, A.C. and Blum A.E. (1986) *Geochim. Cosmochim. Acta*, **50**, 2363–79.