Microstructural evolution of second-phase controlled carbonates in large-scale shear zones under prograde and retrograde conditions.

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Steady state microfabrics of dynamically recrystallized rocks of large-scale shear zones are characterized particularly by (a) phase compositions, (b) physical conditions, and (c) changes of deformation conditions in space and time. Other parameters like matrix chemistry and synkinematic fluids are of minor importance, at least in case of carbonates deformed under natural conditions in the range between 200-400°C.

(a) Second phases in carbonate mylonites, in this study predominantly sheet silicates, have an important influence on shape and grain size of the matrix phase calcite. Due to the pinning effect of second phases, at constant temperature, the mean area-weighted grain size of calcite (D_{cc}) can be expressed by the relationship $D_{cc}=c*(d_p/f_p)^m$ (1), where c is a constant, m=0.3±0.05, d_p the grain size and f_p the volume fraction of second phases. Under constant physical conditions, d_p depends on f_p following the relation $d_p=k*f_p^n$ (2) with a constant k and n=0.15±0.05.

(b) The temperature dependency of equations 1 and 2 can be incorporated by changing both equations into an Arrhenius type form. The resulting equation of second-phase controlled grain growth of calcite is $D_{cc}=c'*exp(^{-Q_{cc}}/_{RT})*(d_p/f_p)^m$ (3). Likewise, temperature dependent grain growth of second-phases can be expressed as $d_p=k'*exp(^{-Q_p}/_{RT})*f_p^n$ (4). C' and k' are new constants, Q_{cc} and Q_p activations energies, R the gas constant and T the deformation temperature in K. Equations 1 and 2 characterize the steady state deformation microfabrics at constant physical conditions where dynamic steady state fabrics are controlled by a balance of nucleation, grain growth, pinning and grain size reducing mechanisms (dynamic recrystallization). In addition, equations 3 and 4 describe the competition between temperature induced grain growth and deformation induced grain size reduction. Interestingly, calcite microfabrics of different large-scale shear zones, which are corrected for a similar second-phase influence, fit all within the error on a linear trend characterized by a change in slope in an Arrhenius type diagram ($logD_{cc}$ vs. $1/T$) at temperatures around 300-350°C. Therefore, resulting activation energies Q_{cc} (for calculation see Geology data repository in Herwegh et al., 2005) are higher for T>300-350°C yielding values of 60±8 kJ/mol (second-phase controlled) and 80±8 kJ/mol (recrystallization controlled) than for T<300-350°C with values of 32±3 kJ/mol (second-phase rich) and 40±3 kJ/mol (pure). These differences in activation energies indicate that different sets of dominant processes are active during deformation at high and low temperatures and in pure and impure mylonites. In a similar way, activation energies Q_p for second-phase grain growth yield an average of 40±7 kJ/mol. In contrast to calcite, the second-phase growth behaviour displays only one linear trend in an Arrhenius plot indicating the presence of one single growth mechanism for all samples investigated.

(c) During thrusting, i.e. deformation, physical conditions change along the thrusts but also with time. Deformation on the retrograde path leads to strain localization, which is characterized by a narrowing of the shear zone width and a distinct grain size reduction of matrix and second phases. In case of grain size reduction, resulting microstructures are similar to those developed at locations with equivalent peak metamorphic conditions at lower temperatures. Therefore, equations 1-4 hold also for deformation on the retrograde path.

In summary, both matrix grains and second phases change their microstructures with changing temperature/stress conditions and affect each other during simultaneous recrystallization cylces. The evolution of coupled grain growth under prograde conditions as well as of grain size reduction on the retrograde path can be displayed in grain coarsening/reduction maps, which can be calculated from equation 3 with substitution of d_p by equation 4 (see Figure 1).

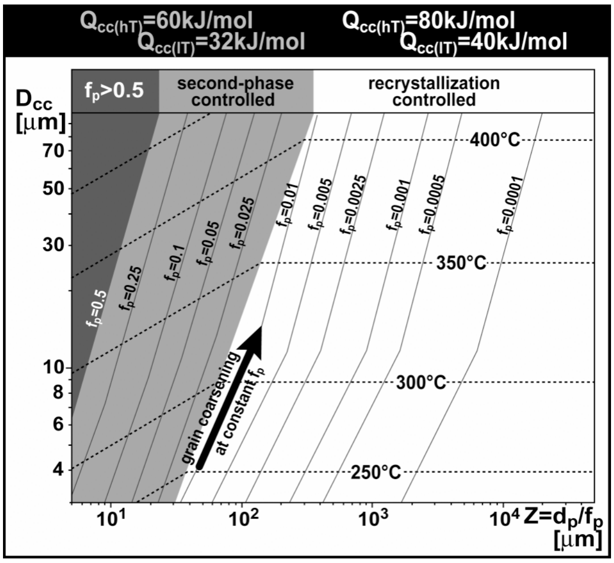

Figure 1. Grain coarsening/reduction map of calcite in second-phase and recrystallization controlled microstructures derived from equation 3 and 4 (D_{cc} = calcite grain size, Z = Zener parameter = d_p/f_p = grain size/volume fraction of second phases, Q_{cc} = activation energies for second-phase (grey letters) and recrystallization (white letters) controlled microstructures for T>300-350°C (hT) and T<300-350°C (lT).

REFERENCES

Herwegh, M., Berger, A. & Ebert, A. (2005): Grain coarsening maps: A new tool to predict microfabric evolution of polymineralic rocks. Geology 33 (10): 801-804.