Coupling of the Chemical and Mechanical evolution of Crenulation Cleavage

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Abstract

In order to better understand the processes that form the world's great mountain belts, it is important to understand how the strength of rocks is influenced by the microstructures within them. The focus of this research is on the development of crenulation cleavage, a very common microstructure found in mountain belts.

Crenulation cleavage forms during multiple stages of deformation. During an early stage of deformation, the minerals in a rock will rearrange and form a planar foliation (S1). During a later stage, the minerals that formed the earlier foliation will rearrange and can form a specific type of new fabric, which is called crenulation cleavage (S2).

The processes, both chemical and mechanical, that are responsible for this rearrangement of minerals are not completely understood and the aim of this research is to gain a better understanding of how they interact to form crenulation cleavage.

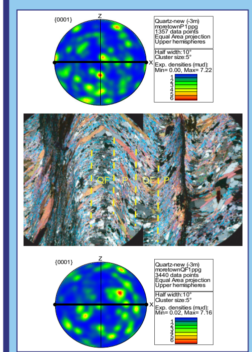
Technical Abstract

Crenulation cleavage is a common microstructure found in mountain belts. Individual aspects of crenulation cleavage have been studied previously, e.g.:

- **geometrical evolution** (Bell and Rubenach, 1983)
- **chemical evolution**: mass balance calculations based on x-ray fluorescence spectrometry (Starkey, 2002) and microprobe analysis (Williams et al., 2001)
- **theoretical formulations** regarding the driving forces for the compositional differentiation: pressure solution (Gray and Durney, 1979) and strain-driven dissolution (Bell et al., 1986)

The aim of this research is to combine numerical modeling, electron backscatter diffraction (EBSD), cathode luminescence (CL) and compositional mapping to explore the coupling of chemical and mechanical processes responsible for crenulation cleavage development.

EBSD



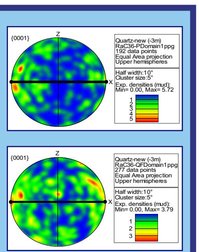
The pole figures represent the orientation of the c-axes projected at an equal area projection, upper hemisphere. The horizontal solid lines indicate the S2 foliation, and the dots represent the lineation.

Results are shown both for a P and QF domain in a Moretown sample (left) and in a Mooselookmeguntic sample (right; the microscopic image of the matching mapped area is shown in the glossary).

These primilary results show that, for the Mooselookmeguntic sample, the preferred orientations in the P-domains are more strongly clustered (maximum mud (multiples of maximum density) =5.72) than the preferred orientations in the QF-domain (max mud =3.79). One possible explanation for this is that there is an orientation that does not dissolve as easily (anisotropic dissolution; Bons and den Brok, 2000) as the other orientations; crystals with this orientation remain in the P-domain, whereas those with other orientations are dissolved and reprecipitated in the QF-domain.

The data from the Moretown formation does not show this difference in mud-value, although it appears as if the clusters from the P-domain seem to lie in a plane, while the clusters from the QF- domain are more scattered.

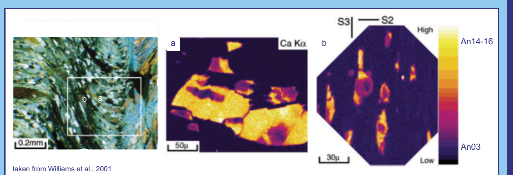
More research will be necessary to draw solid conclusions from this data.



Microprobe analysis

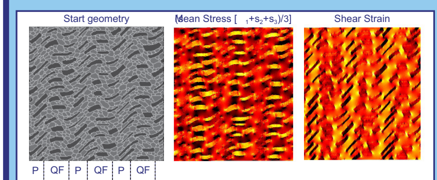
High resolution compositional mapping performed by Williams et al. (2001) on samples from the Moretown Formation of western Massachusetts show two generations of plagioclase. In both domains (QF and P) plagioclase crystals with Ca-poor cores are surrounded by Ca-richer rims. In the crenulation hinges (P-domain) the cores have a distinct elongation and are aligned with the S2 cleavage.

This type of analysis will also be conducted on Mooselookmeguntic samples.



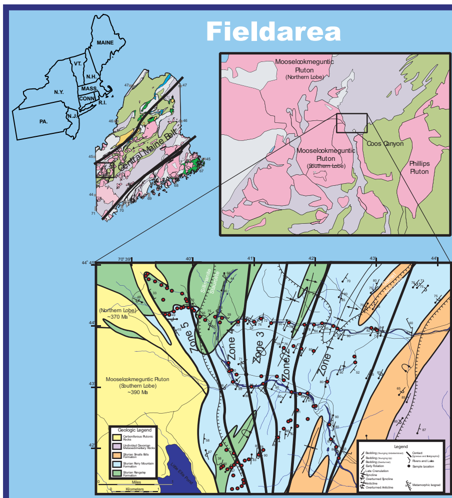
taken from Williams et al., 2001

Numerical modeling



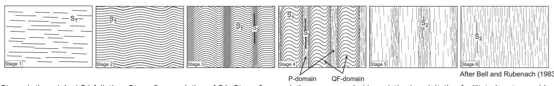
This simplified ELLE model, which is build up by quartz and muscovite minerals (both minerals have complete 3D elasticity tensor components as attributes) and was subjected to an elastic strain using OOF, shows that the quartz-rich regions of QF domains have a higher mean stress than in the P-domains. This may contradict the pressure solution hypothesis for crenulation cleavage development. High elastic shear strains localized in the P-domains may be responsible for dissolution of quartz and feldspar in these zones, and dilatational strains in the QF domains may provide sites of deposition for the dissolved material. Thus, the mass transfer so characteristic of crenulation cleavage development may be driven by strain as opposed to stress.

Fieldarea



Samples collected from the Mooselookmeguntic Pluton aureole in Western Maine contain five different stages of crenulation cleavage, quite similar to the stages of crenulation cleavage development described by Bell and Rubenach (1983). The foliation shows a faint deflection of the regional foliation approximately 2 km from the pluton to an intense, margin parallel foliation adjacent to the pluton.

Some work is done on samples from the Moretown formation, western Massachusetts, which is one of a series of N-S trending lithology belts that occur in western New England, and is interpreted to be the remains of a forearc basin. The Moretown provides an excellent example of small scale folding and crenulation cleavage development, with gradients from uncrenulated domains, through domains with classic crenulation cleavage, to schistose high-strain domains.



After Bell and Rubenach (1983)

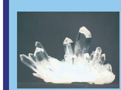
Stage 1: the original S1 foliation. Stage 2: crenulation of S1. Stage 3: crenulation accompanied by solution/precipitation facilitated metamorphic differentiation. Stage 4: growth of new mica's parallel to S2. Stage 5: formation of a spaced cleavage with no relic S1 in the QF-domain. Stage 6: a new homogenized foliation.

Glossary

pluton: the general term for an intrusive igneous body (a body of magma that solidified below the earth's surface)

plagioclase feldspars: group of tecto- or framework silicates. Their composition is usually expressed as their fraction of anorthite (%An; $CaAl_2Si_2O_8$) or albite (%Ab; $NaAlSi_3O_8$):

Albite 100-90 %Ab or 0-10 %An
Oligoclase 90-70 %Ab or 10-30 %An
Andesine 70-50 %Ab or 30-50 %An
Labradorite 50-30 %Ab or 50-70 %An
Bytownite 30-10 %Ab or 70-90 %An
Anorthite 10-0 %Ab or 90-100 %An



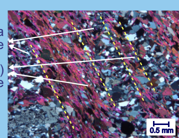
quartz (SiO_2): one of the most common minerals in the earth's upper crust. It has a trigonal/hexagonal crystal system with the c-axis as the long axis

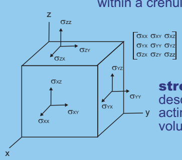
phyllosilicates: a class of silicate minerals. They are also known as sheet silicates and they form parallel sheets of silicate tetrahedra with Si_2O_5 or a 2:5 ratio. Common phyllosilicates are biotite, muscovite, chlorite, talc and smectite

foliation: planar fabric element that occurs penetratively on a mesoscopic scale in a rock (Passchier & Trouw, 2005)

QF-domain: quartz and feldspar rich area (hinge) within a crenulation cleavage structure

P-domain: phyllosilicate rich area (limb) within a crenulation cleavage structure





stress: tensorial quantity with six independent variables describing the orientation and magnitude of force vectors acting on planes of any orientation at a specific point in a volume of material (Passchier & Trouw, 2005)

strain: describes the change of shape of a body when a stress is applied to it; it is expressed as a symmetrical tensor

ELLE: open source software that consists of a (still growing) collection of codes to simulate individual microdynamic processes. Those individual processes can be combined within a single simulation (http://www.materialsknowledge.org/elle/)

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Acknowledgements

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