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Upper–greenschist facies intragrain deformation of albite in mylonitic meta–pegmatite and the influence of crystallographic anisotropy on microstructure formation

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ABSTRACT

We studied the deformation behaviour of albite from Permian meta–pegmatite in Cretaceous upper–greenschist facies shear zones from the Austroalpine Matsch Unit in the Eastern Alps (Italy). Sodium–feldspars from these rocks provide excellent natural examples for studying mechanisms of intragranular deformation under mid–crustal conditions in grains with different angular relations between their (010) planes and the kinematic frame. The studied rocks were deformed at c. 500 °C in localized shear zones with well characterized top–W shear kinematics supposedly during the Cretaceous upper–greenschist facies tectonometamorphic event. Microstructural and chemical data suggest that crystallographic anisotropies in albite exert a strong control on microstructure formation and that albite primarily deformed by a combination of brittle fracturing, dissolution–precipitation and incipient crystal plasticity as a function of the orientation of the crystallographic anisotropy relative to the supposed shortening direction. Dissolution along discontinuities forming stylolites perpendicular to the shortening direction is associated with the precipitation of fine–grained albite with some compositional variability (Ab_{96-98} and Ab_{89-91}) in cracks. New albite precipitates form aggregates with straight segments of high angle grain boundaries, nearly 120° dihedral angles and only a poor or no orientation relation to the hosting clast. Intragranular kinking is related to continuous lattice rotation of up to 15° by a misorientation axis close to albite [100] and the formation of subgrain boundaries with maximum misorientations of 7°. Synthetic microshear zones supposedly nucleated on pre–existing cracks, and are associated with formation of subgrain boundaries in shortening quadrants and cracks together with precipitates of potassium feldspar in extensional quadrants adjacent to the microshear zone. New microstructural and textural data from mylonitic Permian meta–pegmatites document various closely linked crystal plastic and brittle deformation mechanisms and highlight the role of crystallographic anisotropies and their orientation with respect to the kinematic frame in microstructure formation.

1. Introduction

Feldspars are key constituents of the Earth's crust because they are stable over a wide range of rock compositions and P–T conditions. Their deformation and recrystallization behaviour plays an important role in rheological models (e.g. Mehl and Hirth, 2008; Bürgmann and Dresen, 2008) and therefore they have received considerable attention in natural and experimental studies in the past (Vernon, 1975; Tullis and Yund, 1987; Simpson and Wintsch, 1989; Pryer, 1993; Fitz Gerald and Stünitz, 1993; Prior and Wheeler, 1999; Jiang et al., 2000; Heidelbach et al., 2000; McLaren and Pryer, 2001; Imon et al., 2002; Tsurumi et al., 2003; Menegon et al., 2006; McLaren and Reddy, 2008; Menegon et al., 2013), covering a wide spectrum of crustal P–T conditions, at greenschist facies (Prior and Wheeler, 1999; Jiang et al., 2000), amphibolite facies (Leiss et al., 2002; Rosenberg and Stünitz, 2003; Brander et al., 2012; Fukuda et al., 2012; Fukuda and Okudaira, 2013; Menegon et al., 2008) and granulite facies metamorphic grade (Olsen and Kohlstedt, 1984; Kruse et al., 2001). Experimental studies were mainly carried out at high temperatures of >700 °C, with experimental strain rates being larger by several orders of magnitude ($10^{-5}s^{-1} - 10^{-7}s^{-1}$, Heidelbach et al., 2000; McLaren and

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Pryer, 2001; Stünitz et al., 2003) than natural strain rates ($10^{-12}s^{-1}$ – $10^{-16}s^{-1}$, e.g. Rybacki and Dresen, 2004). However, the feldspar deformation mechanisms, in particular the interaction of brittle and crystal plastic deformation and the onset of crystal plasticity in feldspars were focus of recent research and are still debated (McLaren and Pryer, 2001; Stünitz et al., 2003). Earlier studies have reported microkinks in feldspars and interpreted these as the result of brittle failure at sites of dislocation tangles (Tullis and Yund, 1987; Pryer, 1993). Crystal plastic deformation is assumed to occur above 450–550 °C (Fitz Gerald and Stünitz, 1993 and references therein). However, due to perfect cleavage along the (010) and (001) planes, fracturing may also play an important role at higher temperatures (Menegon et al., 2013; Tullis and Yund, 1987). Tullis and Yund (1987) argued that microstructures resembling those associated with crystal plasticity may have been caused by cataclastic flow on the sub–μm scale.

The electron backscatter diffraction (EBSD) method allows to map crystallographic orientations at high spatial resolution (<100 nm lateral resolution) and to characterize grain– and subgrain boundaries based on misorientation angles of neighbouring grains (Prior et al., 1999). This method has successfully been applied to various rock–forming minerals with different crystal symmetries, such as quartz (Stipp and Kunze, 2008), calcite (Bestmann and Prior, 2003), garnet (Prior et al., 2002), K–feldspar (McLaren and Reddy, 2008), albite (Prior and Wheeler, 1999; Jiang et al., 2000) and olivine (Demouchy et al., 2014).

Permian pegmatites in the Austroalpine Matsch Unit in South Tyrol (Italy) were overprinted by localized shear deformation at upper–greenschist facies conditions during the Cretaceous (Schmid and Haas, 1989; Habler et al., 2009). Coarse–grained albite clasts within these mylonitic meta–pegmatites provide excellent natural examples for studying the deformation behaviour of feldspar under P–T conditions of the middle crust.

The aim of this study is to present and discuss the formation of intragranular deformation–related microstructures and textures highlighting the influence of the crystallographic anisotropies in albite clasts and their orientation with respect to the kinematic frame.

2. Methods

2.1. Electron microprobe (EPMA)

Compositional mineral analyses were performed at the Department of Lithospheric Research at the University of Vienna using a Cameca SX100 instrument at an acceleration voltage of 15 KeV, a beam current of 25 nA and a beam diameter of 6 μm for albite feldspar. Natural and synthetic standards were used for calibration. The PAP routine (Pouchou and Pichoir, 1991) was used for matrix corrections. Cations in feldspar are normalized to 8 oxygens and recalculated assuming all Fe as Fe^{3+}. Representative mineral analyses are given in Table 1.

2.2. Electron backscatter diffraction analysis (EBSD)

EBSD analyses were performed on a FEI™ Quanta 3D FEG instrument at the Faculty of Geosciences, Geography and Astronomy at the University of Vienna. The system is equipped with a field–emission electron source and an EDAX™ Digiview IV EBSD camera. Polished thin sections were prepared by first mechanical and then mechano–chemical polishing using a colloidal silica suspension with a pH of 9.2–10 for the final preparation step. Electrical conductivity of the samples was established by very thin carbon coating under high vacuum conditions (<10^{-5} mbar) using a single carbon thread. During EBSD analyses, the sample was tilted to 70° at a working distance of 14 mm. Beam settings were at an acceleration voltage of 15 KeV and a beam current of 4 nA in analytic mode. The OIM™ software v6.2 was used for data collection and processing. EBSD crystallographic orientation mapping was performed by beam scanning with step sizes varying from 0.5 to 2 μm. A 4x4 binning of the EBSD camera resolution was used. General parameters of the Hough settings for indexing 6–12 Hough peaks were a Theta step sizes of 1°, a binned pattern size of 160, a minimum peak distance of 8–15 pixels in Hough space and applying a 9x9 convolution mask. The datasets were cleaned using the "Grain CI (= confidence index) Standardization" and "Neighbor Orientation Correlation" cleanup routines of the OIM™ Analysis software. EBSD data provide information on the spatial arrangement of grains, quantitative grain–size and –distribution information, the geometry of grain–boundary traces and the full crystallographic orientation. In the current study, the crystallographic orientation data are primarily presented as pole figures, whereas microstructures are shown in pattern quality maps (IQ). The latter give pattern contrast values as greyscales and were combined with data for angular misorientations between grains and subgrains. Orientation deviation maps are color coded by rainbow colors for the angular misorientation of each point with respect to a reference point within the corresponding grain. This reference point is either the average orientation of that grain or the point in this grain with the lowest kernel average misorientation.

Table 1
Mineral chemical composition of albite.

Phase generation sample position	Albite Permian	Albite Cretaceous	Albite Cretaceous
	M1201B2 clast	M1201B2 strain shadow	M1201B2 strain shadow
SiO_2	67.92	68.11	66.77
TiO_2	0.01	0.00	0.00
Al_2O_3	20.13	20.06	21.10
Cr_2O_3	0.00	0.00	0.00
Fe_2O_3	0.02	0.02	0.01
MnO	0.02	0.00	0.00
MgO	0.00	0.00	0.01
CaO	0.71	0.55	1.95
Na_2O	11.20	11.13	10.57
K_2O	0.09	0.07	0.06
BaO	0.00	0.02	0.06
Total	**100.09**	**99.95**	**100.54**
Oxygens	8	8	8
Si	2.97	2.98	2.92
Ti	0.00	0.00	0.00
Al	1.04	1.03	1.09
Cr	0.00	0.00	0.00
Fe-III	0.00	0.00	0.00
Mn	0.00	0.00	0.00
Mg	0.00	0.00	0.00
Ca	0.03	0.03	0.09
Na	0.95	0.94	0.89
K	0.01	0.00	0.00
Ba	0.00	0.00	0.00
Total	**4.99**	**4.98**	**4.99**
Xan	0.03	0.03	0.10
Xab	0.96	0.97	0.90
Xor	0.01	0.00	0.00

3. Regional geology

The Matsch Unit is situated at the southern margin of the Austroalpine Ötztal–Stubai Complex (ÖSC). This Unit is lithologically dominated by biotite–sillimanite gneisses and garnet–-staurolite–two mica schists with frequent intercalations of meta–pegmatites (Fig. 1; Ratschiller, 1953). Localized shear zones with largely north–dipping mylonitic foliation, ~E–W trending