Reversely zoned plagioclase in lower crustal meta-anorthosites: An indicator of multistage fracturing and metamorphism in the lower crust

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ABSTRACT

This paper describes the formation mechanism of reversely zoned plagioclase, which has been observed frequently in lower crustal shear zones and is indicative of multistage fracturing and metamorphism in the lower crust, by studying the microstructural and chemical characteristics of plagioclase in sparsely fractured anorthosites and anorthositic mylonites from the Eidsfjord shear zone, Langøy, northern Norway. Based on the field relationship between sparsely fractured anorthosite and anorthositic mylonite, the fracturing of anorthosite occurred before the formation of mylonite. In sparsely fractured anorthosites, transgranular fractures are observed; hydration-reaction products, including Na-rich plagioclase, occur within cracks and fractures, suggesting that hydration reactions occurred during or after fracturing. The hydration reactions in sparsely fractured anorthosites are estimated to have occurred at higher-pressure (~P) amphibolite-facies conditions (~0.9–1.0 GPa and ~550–700 °C). In anorthositic mylonites, which are considered to have initiated by fracturing and subsequent hydration metamorphism at lower-P amphibolite-facies conditions (~0.7 GPa and ~600 °C), recrystallized plagioclase grains often show compositional zoning with an Na-rich core and a Ca-rich rim. Because the compositions of metamorphic plagioclase grains in the sparsely fractured anorthosites and those of the Na-rich cores of the reversely zoned plagioclase in anorthositic mylonites are similar to each other, the Na-rich cores of the matrix plagioclase in the anorthositic mylonites have recrystallized under higher-P amphibolite-facies conditions and then been overgrown or replaced by the Ca-rich rims under lower-P conditions. Consequently, the reversely zoned plagioclase observed frequently in lower crustal shear zones is an indicator of multistage brittle fracturing and subsequent hydration metamorphism during exhumation, providing information relevant to understanding the deep rupture process caused by repeated seismicity alternating with aseismic creep below the seismogenic zone.

Keywords: Anorthositic mylonite, plagioclase, chemical zoning, oxygen isotopic composition, fracturing, lower crust

INTRODUCTION

Major earthquakes, which nucleate in the seismogenic zone, can cause faults to propagate well into the underlying ductile region at the stage of coseismic displacement (e.g., Ellis and Stöckhert 2004; Jiang and Lapusta 2016). This is predicted to create short-term, high differential stresses, high strain rates, and related changes of pore fluid pressure in the ductile region near the tip of a seismically active fault in the lower crust. Fracturing in the lower crust may also increase, at least transiently, the permeability of the damaged rock, thus leading to episodic fluid flow into the damaged rock. Such fluid flow would enhance the formation of hydration-reaction products within the damaged rock (e.g., Jamtveit et al. 2018a). These processes may be recorded as microstructures characterized by initial brittle fracturing followed by hydration metamorphism and viscous deformation in lower crustal shear zones (e.g., Svaahberg and Piazolo 2010; Moecher and Steltenpohl 2011; Mukai et al. 2014; Okudaira et al. 2015, 2017; Leib et al. 2016; Menegon et al. 2017; Petley-Ragan et al. 2018; Jamtveit et al. 2019). Understanding the deep ruptures below the seismogenic zone is important for evaluating the recurrence of major earthquakes in the continental crust (Jiang and Lapusta 2016). The microstructures provide information relevant to understanding the deep rupture process caused by repeated seismicity alternating with aseismic creep below the seismogenic zone.

Varially deformed anorthositic or gabbroic rocks in Langøy, Vesterålen, northern Norway, provide a rare opportunity to study deformation and metamorphic processes in the lower crust. Based on microstructural analyses of plagioclase in anorthositic mylonites, Okudaira et al. (2017) discussed the roles of fracturing and grain-size-sensitive creep during initiation of the ductile shear zone in meta-anorthosite. Soda and Okudaira (2018) described on microstructures indicative of pulverization in some anorthositic mylonites, which possibly results from stress waves with high stress or strain-rate loadings released by a rupturing