Experimental investigation of laumontite $\rightarrow$ wairakite + H$_2$O: A model diagenetic reaction

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ABSTRACT

The rate and mechanism of a key diagenetic reaction, laumontite $\rightarrow$ wairakite + H$_2$O, have been determined in experiments with durations as long as three months at $P_{H_2O} = 100$ MPa and temperatures of 350–450 °C. In the lower temperature range, 350–400 °C, nucleation of wairakite occurred on the smallest laumontite fragments in the starting material. Growth then proceeded by the dissolution of large laumontite grains, transport within the fluid, and precipitation of euhedral to subhedral wairakite. At higher temperatures, 425 and 450 °C, each sample contains two product phases: wairakite and an unidentified plagioclase-like phase. The plagioclase-like silicate was stabilized by the uptake of Na and formed early as $\sim 10$ μm wide skeletal grains along laumontite grain boundaries. The wairakite grains subsequently nucleated on and grew into the interiors of large laumontite grains.

Nucleation rates at 425–450 °C were 10–100 wairakite grains per square meter of laumontite surface per second. Growth rates varied from $1.5 \times 10^{-11}$ m/s at 350 °C to $2.1 \times 10^{-10}$ m/s at 450 °C; the low-temperature data can be fit with an apparent activation energy of 72 ± 13 kJ/mol and a pre-exponential “interface jump distance” of $\sim 1 \times 10^{-18}$ m. This activation energy and these growth rates are comparable to those calculated by Walther and Wood (1984) to characterize interface-controlled reactions in silicates under H$_2$O-saturated conditions. Our data predict transformation rates for geologic conditions that are too fast to account for the commonly observed incomplete natural reaction of laumontite $\rightarrow$ wairakite, indicating that transformation in nature must be limited by slower nucleation rates or by slower intergranular diffusion—perhaps as a result of lower H$_2$O activity or slower heating rates.

INTRODUCTION

The role of fluid in the Earth’s crust is multifaceted and profound. The presence and activity of fluid influence rock deformation, heat flow, the distribution of stable isotopes, the maturation of hydrocarbons, the formation of hydrothermal ore deposits, the earthquake failure process, magma formation, and the state of stress in the crust (Nur and Walder 1990). Processes of enormous economic consequence within the upper crust—hazardous seismicity and the formation, migration, entrapment, and degradation of hydrocarbons—are influenced by devolatilization reactions during diagenesis. However, few kinetic studies have been conducted on materials actively undergoing low-grade metamorphism or diagenesis. Therefore our understanding of the rates at which devolatilization occurs and of the effects devolatilization has on porosity, permeability, and deformation is limited. This paper focuses on a single devolatilization reaction that is active during diagenesis: laumontite $\rightarrow$ wairakite + H$_2$O. Laumontite is a common low-grade metamorphic zeolite, with equilibrium phase relations and thermodynamic properties that are reasonably well understood. Besides being an important mineral in its own right, laumontite breakdown also serves as a model system for polyphase rocks. We report on the rate and mechanism of laumontite breakdown during hydrostatic experiments.

LAUMONTITE AND HYDROCARBONS

Laumontite, CaAl$_2$Si$_4$O$_{12}$·4H$_2$O, is the diagnostic mineral of the zeolite facies (Cho et al. 1986; Liou et al. 1987). It is a widespread, low-grade alteration product of calcic plagioclase, volcanic glass, lithic fragments, calcareous fossils, and other zeolites; it also occurs as precipitates in veins (Boles and Coombs 1977; Helmold and van de Kamp 1984). In oil fields, laumontite most commonly forms within plagioclase crystals and often contains inclusions of sericite and epidote formed during plagioclase breakdown. Laumontite cements develop in feldspathic sandstones and can comprise up to 20 vol% of rocks in petroleum fields (e.g., the Stevens sandstone