Clay minerals as geo-thermometer: A comparative study based on high spatial resolution analyses of illite and chlorite in Gulf Coast sandstones (Texas, U.S.A.)

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ABSTRACT

Phyllosilicates are among the most important stable minerals within the Earth’s crust. Their use as geo-thermometer bears great potential for application to the thermal history of rocks within the stability range of layered silicates and was tested here.

A high-resolution analytical technique combining focused ion beam (FIB) milling and analytical electron microscopy (AEM) analysis has been applied to a series of sandstone core samples from the Gulf Coast (Texas, U.S.A.). The nanoscale compositional variations of K-deficient mica and chlorite flakes show that rim compositions are the most likely to approach equilibrium compositions, whereas core compositions may be relict, especially for illite-like phases. These rim analyses were used to test existing empirical or thermodynamically formulated thermo(baro)meters against maximum temperatures, which are perfectly constrained for the selected samples as they were measured in situ during drilling (100–230 °C and 300–1200 bars). The results show that most of the empirical models overestimate the temperature, while thermodynamic models yields reasonable estimates for diagenetic to anchizonal conditions, especially if the Fe3+ content is taken into account. This study clearly shows that phyllosilicates thermometry is reliable when combined with an analytical technique giving access to the fine-scale compositional variations that may represent local equilibration, whereas using micrometric compositional analysis precludes trustworthy application of such thermometers.

Keywords: Illite, chlorite, zonation, thermometry, diagenesis, Gulf Coast

INTRODUCTION

Phyllosilicates are widespread minerals in most diagenic and low-grade metamorphic rocks. For a long time, their compositional variations have attracted interest as potential markers of diagenesis and burial conditions like temperature (T), pressure (P), rock composition, or fluid availability (e.g., Walshe 1986; Vidal and Parra 2000). These compositional variations reflect the wide possible range of several substitutions in phyllosilicates, e.g., di-tri-octahedral, Tschermak or Fe–Mg exchange. Establishing a quantitative link between composition and formation conditions has therefore been a long pursued goal, with two main approaches: empirical calibrations and thermodynamic modeling.

In the empirical case, Cathelineau and Nieva (1985) and Cathelineau (1988) established a correlation between chlorite tetrahedral Al occupancy (noted □Al) and temperature. Their empirical calibrations were subsequently refined by Kranidiotis and McLean (1987), Jowett (1991), Zang and Fyfe (1995), and Xie et al. (1997) to account for the chlorite Mg and Fe contents, which depend primarily on the bulk-rock composition. These empirical thermometers can be easily implemented, but they provide contrasted, sometimes unrealistic, temperature estimates (e.g., De Caritat et al. 1993; Essene and Peacor 1995; Vidal and Parra 1999; Parra 2001). More robust thermodynamic solutions have been proposed (Helgeson et al. 1978; Helgeson and Aagaard 1985; Walshe 1986; Aagard and Jahren 1992; Hutcheon 1990; Vidal and Parra 2000; Vidal et al. 2001, 2005, 2006; Parra et al. 2002; Inoue et al. 2009; Dubacq et al. 2010), but they require knowledge of the thermodynamic properties for numerous end-members as well as solid-solution mixing parameters.

The aim of the present study is to compare the results of such thermometers when applied to a low-temperature, diagenetic sample series of well cores for which a direct, in situ physical measure of temperature and pressure is available. Indeed, most chlorite and illite thermometers were calibrated either in specific conditions, e.g., a hydrothermal system (Cathelineau and Nieva 1985), or at relatively high temperatures that were indirectly derived from petrological data, like phase-equilibria, fluid-inclusion, or vitrinite-reflectance thermometry.

In addition, several generations of clay minerals showing various compositions generally coexist in the same rock sample, from detrital to authigenic to metamorphic, either as discrete crystals in distinct sites, or as zoned crystals with successive overgrowths on relict cores, which may record part of the clay history. To be able to decipher this record in spite of the small grain sizes and expectedly fine scale of the chemical features, a high spatial analytical resolution is needed. The present study takes advantage